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Regioselective Protection Strategies for D-Xylopyranosides[1a]

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The acylation of D-xylopyranosides can be effected at any position by selective hydroxyl activation with dibutyltin oxide in refluxing benzene and proper choice of starting anomer. Methyl 4-*O*-benzyl-β-D-xylopyranoside, available from methyl 2,3-*O*-isopropylidene-β-D-xylopyranoside, provides the 2- and 3-benzoates, which are easily separable in 85% combined yield. Methyl and allyl β-D-xylopyranosides, when treated with 1 equiv of dibutyltin oxide and subsequently with benzoyl chloride (1 equiv), yield their corresponding 4-benzoates (80%). The use of 2 equiv of benzoyl chloride provides the 3,4-dibenzoates in excellent yield (90%). The clean conversion to mono- or dibenzoates, depending on the amount of benzoyl chloride added, suggests that the intermediate stannylene acetals provide different activation levels. A pathway involving acylation of an intermediate dibutylchlorostannyl ether is proposed to explain the observed phenomenon. This sequential selective activation is used to afford protection and differentiation of the 3- and 4-positions with a one-pot synthesis of methyl 4-*O*-benzoyl-3-*O*-(chloroacetyl)-β-D-xylopyranoside. Methyl and benzyl α-D-xylopyranosides afford the 2,4-dibenzoates in good yield (>80%) demonstrating 1,3-activation of a triol system. This protection strategy is used to prepare benzyl *O*-(2,3,5-tri-*O*-benzoyl-α-L-arabinofuranosyl)-(1→3)-2,4-di-*O*-benzoyl-α-D-xylopyranoside from D-xylose and L-arabinose. In the final step, the silver triflate catalyzed glycosylation of benzyl 2,4-di-*O*-benzoyl-α-D-xylopyranoside by 2,3,5-tri-*O*-benzoyl-α-L-arabinofuranosyl chloride is accomplished in 91% yield.

Introduction

Arabinoxylans are important components of the cell walls of grass and legume forage plants. The (1→4)-β-D-xylopyranan backbone of these polymers carries occasional α-L-arabinofuranosyl branches at the 2- and 3-positions of the D-xylose units.[2] Some of the α-L-arabinofuranosyl units are also esterified, through the 5-position, to *p*-coumaric and ferulic acids.[3] These hydroxycinnamic acids may in turn be etherified to lignin, providing a cross-link between lignin and polysaccharide[4] which would undoubtedly affect both cell wall development and degradation. Our studies concerning the regiochemistry of these covalent interactions require appropriate model compounds, and in particular we desire suitably protected D-xylopyranosides for the synthesis of feruloylated and *p*-coumaroylated di- and trisaccharides.

The classic approach to the protection of D-xylopyranosides is via methyl, benzyl, or allyl 2,3-anhydro-β-D-ribopyranoside.[5] Placement of a protective substituent at the 4-position and subsequent opening of the 2,3-anhydro ring provides a variety of useful derivatives.[6] However, the length of this synthesis (seven steps from D-arabinose to a 4-O-protected xyloside) makes the exploration of alternatives attractive, as shown in a recent report[7] from one of our laboratories. In the cited work, an acetal was obtained directly from methyl β-D-xylopyranoside by treatment with 2-methoxypropene/HCl in DMF. The acetal was fully characterized as the 2,3-*O*-isopropylidene derivative **3** by detailed analysis of the ^{1}H NMR spectrum of its 4-triflate.

In the present work, we converted **3** into additional protected derivatives **4** and **5** and studied the partial acylation of the stannylene acetals of alkyl D-xylopyranosides. This procedure yielded a series of derivatives in which the *acylation site(s) depend(s) on the amount of acyl chloride added and the anomeric configuration of the starting material.* These results, and their significance in strategies for D-xylopyranoside protection and arabinoxylan oligosaccharide synthesis, are the subject of this paper.

Results

In our hands, the acid-catalyzed reaction of 2-methoxypropene with methyl β-D-xylopyranoside gave a fully substituted derivative **2**, isolable in 69% yield by silica gel chromatography. In addition to a cyclic acetal (*O*-isopropylidene) group, this compound incorporated a mixed acetal (1-methoxy-1-methylethyl) substituent, which was removed by treatment with methanol containing a little *p*-toluenesulfonic acid.[8,9] The recrystallized cleavage product **3** had mp 73–75 °C and $[\alpha]_D$ −41°, in contrast with the values (mp 138–139 °C and $[\alpha]_D$ −17.3°) previously reported.[7] Examination of the derived benzoate **5** nevertheless indicated the 2,3-*O*-isopropylidene structure for the

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(2) Chesson, A.; Gordon, A. H.; Lomax, J. *Carbohydr. Res.* **1985**, *141*, 137.

(3) (a) Kato, A.; Azuma, J.; Koshijima, T. *Chem. Lett.* **1983**, *137*. (b) Mueller-Harvey, I.; Hartley, R. D.; Harris, P. J.; Curzon, E. H. *Carbohydr. Res.* **1986**, *148*, 71.

(4) (a) Scalbert, A.; Monties, B.; Lallemand, J.-Y.; Guittet, E.; Rolando, C. *Phytochemistry* **1985**, *24*, 1359. (b) Iiyama, K.; Lam, T. Y. T.; Stone, B. A. *Phytochemistry* **1990**, *29*, 733. (c) *Plant Cell Wall Polymers*; Lewis, N. G., Paice, M. G., Eds.; ACS Symposium Series 299; American Chemical Society: Washington, DC, 1989.

(5) (a) Hough, L.; Jones, J. K. N. *J. Chem. Soc.* **1952**, 4349. (b) Garegg, P. J. *Acta Chem. Scand.* **1960**, *14*, 957. (c) Takeo, K.; Nakagen, M.; Teramoto, Y.; Nitta, Y. *Carbohydr. Res.* **1990**, *201*, 261.

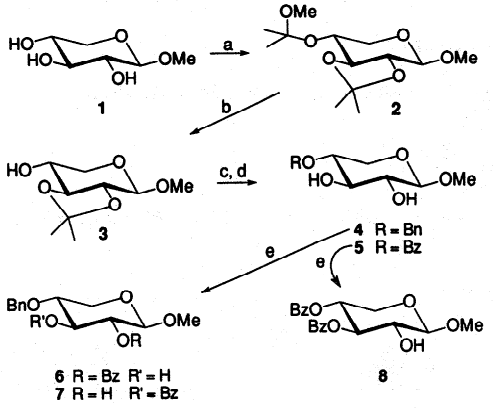
(6) Petráková, E.; Kováč, P. *Carbohydr. Res.* **1982**, *101*, 141.

(7) Naleway, J. J.; Raetz, C. R. H.; Anderson, L. *Carbohydr. Res.* **1988**, *179*, 199.

(8) Barili, P. L.; Berti, G.; Catelani, G.; Colonna, F.; Marra, A. *Tetrahedron Lett.* **1986**, *27*, 2307.

(9) Takeo et al.[5c] have prepared the thioglycoside analogue of **3** by the reaction of the parent thioglycoside with 2-methoxypropene/HCl in DMF then treatment of the crude $CHCl_3$-extracted reaction product with a small amount of acid.

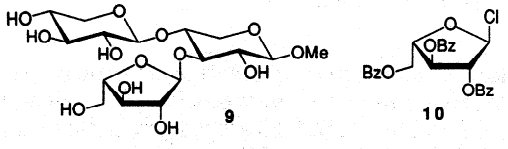
Scheme I. Isopropylidenation/Dibutyltin Oxide-Mediated Acylation Protection Strategy[a]



[a] Key: (a) 2-methoxypropene/TFA, 40 °C; (b) *p*-TsOH/MeOH, 0 °C; (c) BnBr/KOH, 0 °C or BzCl/py (d) H^+ resin, MeOH (48% yield overall, steps a–d); (e) Bu_2SnO/PhH at reflux; BzCl, 0 °C.

cyclic acetal, and this was further confirmed by conversion of the acetal into its triflate, whose ^1H spectrum was superimposable on that of the previous preparation.

Our synthetic approach to target oligosaccharides such as **9** envisioned the coupling of 2,3,5-tri-*O*-benzoyl-α-L-arabinofuranosyl chloride (**10**) with a 4-*O*-benzyl-β-D-xylopyranoside derivative. Removal of the benzyl group,



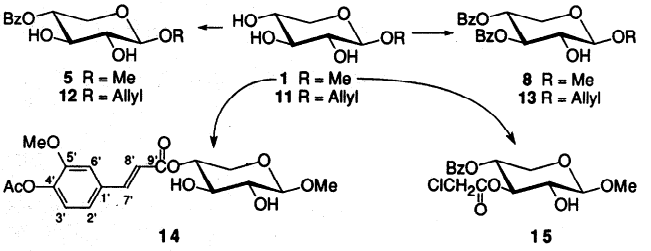
coupling with 2,3,4-tri-*O*-acetyl-α-D-xylopyranosyl bromide, and deprotection would give the desired trisaccharide. However, initial attempts to react **4** with **10** gave a complex mixture containing predominantly diglycosylated material, and therefore a strategy for the further regioselective protection of **4** was required.

Benzoylation after stannylene acetal formation with dibutyltin oxide (Bu_2SnO)[10,11] was appropriate for investigation on the basis of results obtained with methyl 4,6-*O*-benzylidene-β-D-glucopyranoside.[12,13] Overnight treatment of **4** with 1 equiv of Bu_2SnO in refluxing benzene with continuous removal of water (Dean-Stark trap) afforded a clear solution which, upon cooling (0 °C) and the subsequent addition of benzoyl chloride (1 equiv), gave the expected mixture of **6** and **7** (58:42). The two compounds were easily separated by silica gel chromatography in 85% combined yield (Scheme I). By contrast, benzoylation of stannylated **5** was highly selective for the 3-position giving almost exclusively the 3,4-di-O-substituted material **8** (83%). The substitution ratio (O-3:O-2) was 9.2:1 with methyl 2,4-di-*O*-benzoyl-β-D-xylopyranoside being isolated in 9% yield.

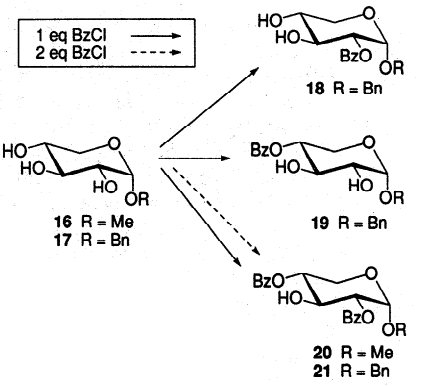
Methyl β-D-xylopyranoside (**1**) provided mono- or disubstituted products depending on the amount of benzoyl chloride added. The addition of benzoyl chloride (1 equiv) to stannylated **1** gave **5** in over 80% yield (Scheme II). Thus, the Bu_2SnO method is superior to the isopropylidenation route for the preparation of 4-*O*-acyl-substituted materials. The addition of 2 equiv of benzoyl chloride gave **8** in greater than 90% yield. The same

(10) David, S.; Hanessian, S. *Tetrahedron* **1985**, *41*, 643.
(11) Reginato, G.; Ricci, A.; Roelens, S.; Scapecchi, S. *J. Org. Chem.* **1990**, *55*, 5132.
(12) Takeo, K.; Shibata, K. *Carbohydr. Res.* **1984**, *133*, 147.
(13) Grindley, T. B.; Thangarasa, R. *Can. J. Chem.* **1990**, *68*, 1007.

Scheme II. Dibutyltin Oxide-Mediated Acylation of Alkyl β-D-Xylopyranosides



Scheme III. Dibutyltin Oxide-Mediated Acylation of Alkyl α-D-Xylopyranosides



results were obtained when starting with allyl β-D-xylopyranoside (**11**), **12** and **13** being isolated in 81 and 90% yields, respectively.

The major impurities in the monobenzoylation products of the alkyl β-D-xylopyranosides were the 3,4-dibenzoates. The formation of the disubstituted compounds can be kept to a minimum by the slow addition of benzoyl chloride. It is also important to avoid gel formation while cooling the stannylene acetal solution, as insufficient mixing during benzoyl chloride addition will result in a higher yield of the disubstituted products.

To illustrate the use of acid chlorides other than benzoyl chloride, methyl 4-*O*-(4-*O*-acetylferuloyl)-β-D-xylopyranoside (**14**), which contains the known 4-*O*-feruloyl-D-xylopyranosyl linkage,[14] was prepared in 60% yield (Scheme II). The total efficiency of acid chloride use was 88%; the 3,4-disubstituted material was isolated in 15% yield. The introduction of two different acyl groups was demonstrated by the preparation of crystalline methyl 4-*O*-benzoyl-3-*O*-(chloroacetyl)-β-D-xylopyranoside (**15**), isolated in 50% yield without chromatography after successive treatments of stannylated **1** with benzoyl chloride and chloroacetyl chloride.

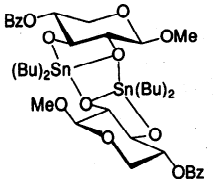
The benzoylation of activated methyl (**16**) and benzyl (**17**) α-D-xylopyranosides (1 equiv Bu_2SnO, 1 equiv of BzCl) gave mixtures of three compounds, which could be separated by silica gel chromatography. Compound **17** afforded benzyl 2-*O*-benzoyl- (**18**, 44%), benzyl 4-*O*-benzoyl- (**19**, 29%), and benzyl 2,4-di-*O*-benzoyl-α-D-xylopyranoside (**20**, 14%) (Scheme III). The reaction was complete within 10 min as indicated by the disappearance of benzoyl chloride, and prolonged treatment did not change the product ratio. The use of 2 equiv of benzoyl chloride with activated **16** and **17** cleanly furnished the 2,4-dibenzoates in over 80% yield. Thus, stannylene acetal activation of alkyl α-D-xylopyranosides allows the simultaneous protection of the 2- and 4-positions, leaving the 3-hydroxyl open to further manipulation.

(14) Ishii, T.; Hiroi, T. *Carbohydr. Res.* **1990**, *206*, 297.

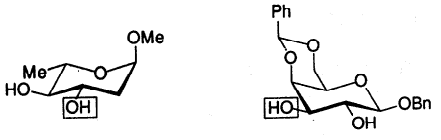
Discussion

Alkyl β-D-Xylopyranosides. Isolated trans diol systems with flanking equatorial substituents, as are found in pyranosides **4** and **5**, typically do not show a preference for benzoylation at either position following stannylene acetal activation, but rather provide mixtures as exemplified by the behavior of **4** and of methyl 4,6-*O*-benzylidene-β-D-glucopyranoside. Indeed, the product ratio obtained with **4** (**6**:**7** = 58:42) is quite similar to that reported by Takeo and Shibata[12] for methyl 4,6-*O*-benzylidene-β-D-glucopyranoside (2-*O*-Bz:3-*O*-Bz = 56:44).

The preparation of **8** in 83% yield from activated **5** was somewhat surprising. The reactive species of stannylene acetals are generally considered to be dimers having in each subunit one dicoordinated and one tricoordinated oxygen.[13] Acylation is thought to occur at the dicoordinated oxygen, with regioselectivity depending on the formation and subsequent substitution of one of the possible acetals of suitable structure. On this hypothesis, a possible intermediate in the benzoylation of **5** at position **3** would be an acetal such as the one shown below, its formation and/or reactivity being favored when the substituent on O-4 is benzoyl, but not when it is benzyl. The basis for this apparent directing effect of the 4-*O*-benzoyl group is not evident.

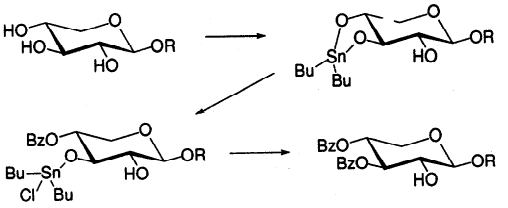


Diequatorial diols that possess either an adjacent methylene or adjacent cis axial substituent undergo preferential stannylene-activated acylation of the hydroxyl next to these sites, as has been observed for methyl 2,6-dideoxy-α-L-*arabino*-hexopyranoside[15] and benzyl 4,6-*O*-benzylidene-β-D-galactopyranoside.[13,16] Thus, the facile benzoylation of the 4-position of **1** and **11** can be explained by the presence of the methylene site at C-5 with the intermediate stannylene acetal being a dimer where the C-4 oxygen is dicoordinated. The monobenzoylation results obtained in this work are quite similar to those obtained by Tsuda et al.,[17] who refluxed **1** and Bu_2SnO in methanol and subsequently benzoylated in dioxane. Their yield of **5** was 77.5% with the major byproduct being **8** (14.1%). The results obtained with **1** and **11** also reflect, in a general fashion, inherent hydroxyl reactivities toward benzoylation and sulfonylation as determined at low temperatures in pyridine.[18] However, the relative differences in pyridine are not as significant as those obtained with stannylene acetal activation.



Reginato et al.[11] have shown that acyclic diols can be selectively benzoylated at the more hindered hydroxyl under essentially the same reaction conditions as used in our work. After formation of the desired monobenzoylated product their reactions were "quenched" by the addition of a trialkylsilyl chloride, which protected the remaining oxygen. Silylation without added base/catalyst implies that the remaining oxygen was also activated, albeit to a lesser degree. The activated intermediate must be a dibutylchlorostannyl ether since it is not possible to form another stannylene acetal, at least intramolecularly. Thus, the addition of 2 equiv of benzoyl chloride to an activated diol should provide disubstitution as found here for stannylated **1** and **11**. We have also found that the addition of 2 equiv of benzoyl chloride to the stannylene acetal of 1,2-propanediol provides the dibenzoate in high yield.

Scheme IV. Proposed Pathway for the 3,4-Di-*O*-benzoylation of Alkyl β-D-Xylopyranosides



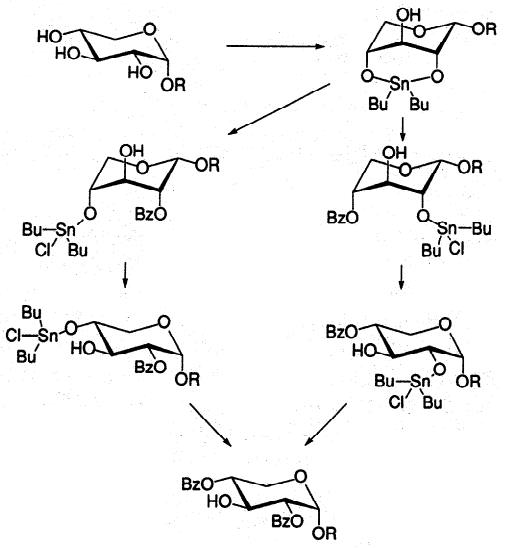
The proposed pathway for the benzoylation of alkyl β-D-xylopyranosides is shown in Scheme IV. The presence of the methylene group at C-5 favors formation of an Sn–O linkage at the 4-position, which leads to formation of a 3,4-stannylene acetal. Benzoylation of O-4 creates a 3-dibutylchlorostannyl ether which undergoes an additional benzoylation in the presence of a second equivalent of benzoyl chloride, providing the 3,4-dibenzoate and dibutyltin dichloride.

The synthesis of methyl 4-*O*-(4-*O*-acetylferuloyl)-β-D-xylopyranoside (**14**, Scheme II) demonstrates the use of acid chlorides other than benzoyl chloride. Deacetylation (piperidine, 95% EtOH) provides a compound with ferulic acid linked to the 4-position of a D-xylopyranosyl unit. This type of ester linkage has recently been found in the cell walls of bamboo,[14] and the model can be used for characterizing the substrate specificity of ruminant bacterial and fungal esterases.[19] The one-pot preparation of crystalline methyl 4-*O*-benzoyl-3-*O*-(chloroacetyl)-β-D-xylopyranoside (**15**) is an extremely simple method for the combined differentiation and protection of the 3- and 4-position based on the two distinct levels of activation observed for stannylated **1** and **11**. Acylation of the remaining C-2 hydroxyl would furnish a material which could be converted to a D-xylopyranosyl halide and subsequently used in 1,2-trans glycosylation reactions. Removal of the chloroacetyl group followed by coupling with another glycosyl halide would afford a trans-linked trisaccharide in a minimum number of steps.

Alkyl α-D-Xylopyranosides. Stannylene acetal mediated acylation of compounds such as methyl 4,6-*O*-benzylidene-α-D-glucopyranoside and methyl 4,6-*O*-benzylidene-β-D-galactopyranoside (i.e., compounds having a trans equatorial diol system flanked by one axial and one equatorial substituent) shows activation of the oxygen adjacent to the axial site.[13,16,20] Thus, in the case of alkyl α-D-xylopyranosides O-2 should be activated, and the presence of the C-5 methylene group dictates that O-4 would also be activated. The apparent lack of selectivity in the acylation of stannylated **16** and **17** with 1 equiv of

(15) Monneret, C.; Gagnet, R.; Florent, J.-C. *J. Carbohydr. Chem.* **1987**, *6*, 221.
(16) David, S.; Thieffry, A. *J. Chem. Soc., Perkin Trans. 1* **1979**, 1568.
(17) Tsuda, Y.; Haque, M. E.; Yoshimoto, K. *Chem. Pharm. Bull.* **1983**, *31*, 1612.
(18) (a) Chalk, R. C.; Ball, D. H. *Carbohydr. Res.* **1973**, *28*, 313. (b) Kondo, Y. *Carbohydr. Res.* **1982**, *107*, 303.
(19) Hatfield, R. D.; Helm, R. F.; Ralph, J. *Anal. Biochem.* **1991**, *194*, 25.
(20) (a) Munavu, R. M.; Szmant, H. H. *J. Org. Chem.* **1976**, *41*, 1832. (b) Holzapfel, C. W.; Koekemoer, J. M.; Marais, C. F. *S. Afr. J. Chem.* **1984**, *37*, 19.

Scheme V. Proposed Pathway for the 2,3-Di-*O*-benzoylation of Alkyl α-D-Xylopyranosides



benzoyl chloride can thus be ascribed to the combined presence of a methylene group at the 5-position and an α-disposed aglycon.

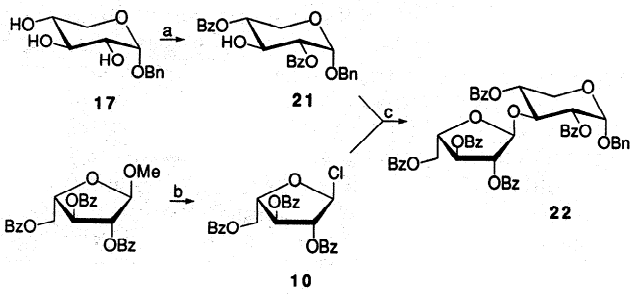
The simplest explanation for the observed results with alkyl α-D-xylopyranosides is the formation of a 2,4-stannylene acetal as shown in Scheme V. Two dimerized 2,4-stannylene acetals would be present, one with O-2 dicoordinated (and hence activated) and the other with O-4 activated. Acylation of the dicoordinated sites would provide the 2- and 4-dibutylchlorostannyl ethers, which would undergo further acylation with a second equivalent of benzoyl chloride. The distinct activation levels observed with the β-anomers are not evident because of the two different stannylene acetals initially present. Although the existence of stannylene acetals bridging 1,3-disposed hydroxyls on a pyranose ring, e.g., the postulated 2,4-stannylene acetal, has not been confirmed experimentally, the analogous 2,4-phenylboronate of methyl α-D-xylopyranoside is formed in high yield under similar Dean-Stark conditions in benzene.[21]

A second possible pathway is the formation of a mixture of the 2,3- and 3,4-stannylene acetals. Substitution of the activated oxygens at the 2- and 4-positions, respectively, lead to 3-*O*-dibutylchlorotin intermediates which rearrange to form two acylated stannylene acetals. The stannyl ether does not undergo acylation in this reaction scheme. The newly formed 2,3-stannylene acetal is an isolated trans diequatorial system with an α-aglycon and so undergoes 2-O-benzoylation. The companion 3,4-stannylene acetal is an isolated trans diequatorial system with a methylene site adjacent to the 4-hydroxyl and undergoes 4-O-benzoylation. The second step of both reactions leads to the 2,4-dibenzoate.

Application of the Protection Strategy. D-Xylose can be converted into a mixture of the benzyl D-xylopyranosides from which the α-anomer **17** (Scheme VI) is isolable in 31% yield by selective crystallization from Et_2O/light petroleum ether. Dibutyltin oxide mediated acylation of **17** gave **21** in 90% yield (after silica gel chromatography), furnishing a selectively protected nucleophile in two steps from the reducing sugar. Methyl α-L-arabinofuranoside tribenzoate, available from L-arabinose,[22] was easily converted to crystalline **10** in 83%

(21) Ferrier, R. J.; Prasad, D.; Rudowski, A.; Sangster, I. *J. Chem. Soc. C* **1964**, 3330.

Scheme VI. Application of the Protection Strategy to Disaccharide Synthesis[a]



[a] Key: (a) Bu_2SnO/PhH at reflux; BzCl (2 equiv) at 0 °C; (b) DCMME/$SnCl_4$ in CH_2Cl_2 (84%); (c) Ag Triflate/collidine in CH_2Cl_2 (91%).

yield by treatment with dichloromethyl methyl ether (DCMME)[23] and $SnCl_4$ in CH_2Cl_2. Zinc chloride was not an effective catalyst for the transformation. Perhaps the use of $SnCl_4$ will provide a general means for the direct conversion of acylated methyl furanosides into the furanosyl halides by treatment with DCMME. The L-arabinofuranosyl chloride is much more stable than the corresponding bromide, and **10** has been stored at room temperature, desiccated over P_2O_5, for periods in excess of 6 months without any noticeable degradation. Silver triflate catalyzed coupling of **10** and **21** in CH_2Cl_2 afforded **22** in high yield (91%) with a minimum of excess halide (1.33 equiv). The 1,2-trans glycosidic linkage was indicated by the characteristic H-1,2 coupling constant (<1 Hz) and C-1 chemical shift (107.4 ppm) of the L-arabinofuranosyl moiety. Previous syntheses of arabinoxylans[24] have also proceeded with high-yielding glycosylation reactions, although not with the same efficiency with respect to preparation of the protected D-xylopyranoside precursors.

Summary

Dibutyltin oxide mediated acylation of D-xylopyranosides is the key process in a synthetic plan for the preparation of protected D-xylopyranosides. Complemented with the use of 2-methoxypropene/TFA, it leads to a variety of intermediates useful for the synthesis of β-D-xylopyranose-containing oligosaccharides. Stannylated alkyl β-D-xylopyranosides undergo selective acylation of the 3- and 4-positions. Activated alkyl α-D-xylopyranosides, with the combined presence of a C-5 methylene and an α-aglycon, afford substitution of the 2- and 4-positions. The 2,4-di-*O*-acyl-α-D-xylopyranosides formed in one step are complementary to the products obtained from alkyl β-D-xylopyranosides.

Experimental Section

Melting points are uncorrected. Evaporations were conducted under reduced pressure at temperatures less than 42 °C. Solutions in organic solvents were dried with Na_2SO_4 and filtered before evaporation to syrups. Further elimination of organic solvents as well as drying of the residues was accomplished under high vacuum (75–100 mTorr) at room temperature. Optical rotations were obtained at 20 °C, and NMR data were acquired at 360 MHz (24–27 °C) in acetone-d_6 (99.5 atom %; δ_C 29.8 ppm, δ_H 2.04 ppm), unless stated otherwise. Column chromatography was performed with silica gel 60 (230–400 mesh) and thin-layer chromatography was done on silica gel 60-F254 plates with carbohydrate visual-

(22) Fletcher, H. G. *Methods Carbohydr. Chem.* **1963**, *2*, 228.
(23) Grob, H.; Farkas, I.; Bognár, R. *Z. Chem.* **1978**, *18*, 201.
(24) (a) Hirsch, J.; Petráková, E.; Schraml, J. *Carbohydr. Res.* **1984**, *131*, 219. (b) Koto, S.; Morishima, N.; Takenaka, K.; Uchida, C.; Zen, S. *Bull. Chem. Soc. Jpn.* **1985**, *58*, 1464. (c) Hirsch, J.; Petráková, E. *Chem. Papers* **1989**, *43*, 395.

ization with either UV light or charring (5% H_2SO_4 in 95% EtOH). Organotin reaction byproducts were visualized by charring with phosphomolybdic acid reagent (5% $12MoO_3 \cdot H_3PO_4$ in 95% EtOH).

General Procedure for Dibutyltin Oxide Mediated Acylations. Alkyl D-xylopyranoside (1.0 mmol) and dibutyltin oxide (1.03 mmol) were suspended in benzene (35 mL), and the mixture was stirred at reflux overnight, with the azeotropic removal of water (Dean-Stark trap). The resulting hazy-to-clear solution was cooled under N_2 in an ice–water bath and stirred while the acyl chloride (1.05 or 2.05 mmol) was added via a syringe. After addition was complete the flask was removed from the bath and allowed to reach room temperature. TLC indicated that the reaction was typically complete within 30 min, but it was usually left to continue for at least 2 h. The crude mixture was evaporated to a syrup and the product taken up in acetonitrile and washed (3×) with light petroleum ether (which eliminated a portion of the organotin compounds). The syrup could also be washed directly with petroleum ether to eliminate almost all of the organotin contaminants (with some loss of desired material). Subsequent silica gel chromatography of the appropriate fraction afforded the purified acylated derivatives.

Methyl 2,3-*O*-Isopropylidene-4-*O*-(1-methoxy-1-methylethyl)-β-D-xylopyranoside (2). Methyl β-D-xylopyranoside (1, g, 6.11 mmol) was suspended in DMF (2 mL) and heated to 40 °C. Trifluoroacetic acid (1 μL) was added followed by 2-methoxypropene (2 mL, 20.8 mmol). The solution cleared rapidly and was left for 12 h with stirring. TLC (19:1 $CHCl_3$–EtOAc) at this time indicated that there were three products, one major (R_f 0.50) and two minor (R_f 0.55, 0.25). The reaction was quenched with Et_3N (20 μL), and the mixture was diluted with CH_2Cl_2 and washed with water (2×). The organic phase was processed and the crude syrup submitted to silica gel chromatography (40 g of silica packed in CCl_4). Elution with CCl_4–acetone–Et_3N (40:1:0.01) furnished 2 as a clear syrup in greater than 95% purity (1.16 g, 68.8%): $[\alpha]_D$ −41° (*c* 3.7 in acetone); δ_C 25.5 and 25.9 (OC(OCH_3)(CH_3)$_2$), 26.8 and 27.1 (C(CH_3)$_2$), 48.9 (OC(OCH_3)(CH_3)$_2$), 55.8 (OCH_3), 67.3 (C-5), 69.4 (C-4), 77.6 (C-2), 80.2 (C-3), 101.2 (OC(OCH_3)(CH_3)$_2$), 103.2 (C-1), 111.0 (*C*(CH_3)$_2$); δ_H 1.28, 1.30, 1.35, and 1.36 (4 × 3 H, s's, CCH_3), 3.18 (3 H, s, OC(OCH_3)(CH_3)$_2$), 3.25–3.32 (2 H, m, H-2 and H-5a), 3.40 (3 H, s, OCH_3), 3.54 (1 H, t, $J_{3,2} + J_{3,4}$ = 18.4 Hz, H-3), 3.95–4.02 (2 H, m, H-4 and H-5e), 4.52 (1 H, d, $J_{1,2}$ = 7.3 Hz, H-1). The material did not provide an adequate elemental analysis, presumably due to retained CCl_4.

Methyl 2,3-*O*-Isopropylidene-β-D-xylopyranoside (3). Syrupy 2 (1.03 g, 3.73 mmol) was diluted with MeOH (12 mL) and cooled in an ice–water bath. An aliquot of *p*-toluenesulfonic acid in MeOH (1 mg/mL, 200 μL) was added with stirring, and the reaction was monitored closely by TLC. Cleavage of the mixed acetal was complete in 10 min, at which time the reaction was neutralized by the addition of strongly basic ion-exchange resin (OH^- form). The solution was filtered, and the filtrate was evaporated to a syrup, diluted with CH_2Cl_2, and dried. Evaporation to a syrup and crystallization from Et_2O–light petroleum ether afforded 3 in two crops as needles (620.2 mg, 81.4%): mp 73–75 °C; $[\alpha]_D$ −41° (*c* 2.5 in $CHCl_3$) [lit.[7] mp 138–139 °C, $[\alpha]_D$ −17.3° (*c* 1.2 in $CHCl_3$)]; δ_C 26.7 and 27.0 (C(CH_3)$_2$), 55.9 (OCH_3), 68.2 (C-5), 69.7 (C-4), 77.4 (C-2), 81.8 (C-3), 103.5 (C-1), 111.0 (*C*(CH_3)$_2$); δ_H 1.35 (2 × 3 H, s's, CCH_3), 3.19 (1 H, dd, $J_{5a,5e}$ = 11.4 Hz, $J_{5a,4}$ = 7.7 Hz, H-5a), 3.20 (1 H, dd, $J_{2,1}$ = 7.5 Hz, $J_{2,3}$ = 9.7 Hz, H-2), 3.40 (3 H, s, OCH_3), 3.48 (1 H, t, $J_{3,2} + J_{3,4}$ = 18.4 Hz, H-3), 3.86 (1 H, m, H-4), 3.92 (1 H, dd, $J_{5e,4}$ = 5.2 Hz, H-5e), 4.49 (0.8 H, d, $J_{OH,4}$ = 4.9 Hz, 4-OH), 4.51 (1 H, d, H-1). Anal. Calcd for $C_9H_{16}O_5$: C, 52.93; H, 7.90. Found: C, 52.48; H, 7.85.

Methyl 4-*O*-Benzyl-β-D-xylopyranoside (4). Crystalline 3 (694 mg, 3.40 mmol) was dissolved in DMF (10 mL) under an atmosphere of N_2 and cooled in an ice–water bath. Powdered KOH (1.81 g) was added, followed by benzyl bromide (425 μL, 3.7 mmol), and the mixture was well stirred for 30 min. The reaction product was then diluted with CH_2Cl_2 and filtered. Subsequent washing with water (3×) afforded a syrup, which was diluted with MeOH (50 mL) and stirred slowly overnight with strongly acidic ion-exchange resin. Complete conversion was noted by TLC (R_f 0.1, 19:1 $CHCl_3$–EtOAc), and the resulting mixture was processed in standard fashion. Crystallization from absolute EtOH–light petroleum ether gave 4 as small white needles (738 mg, 85.5%): mp 104–105 °C; $[\alpha]_D$ −81° (*c* 1.58 in $CHCl_3$) [lit.[25] mp 99–100 °C, $[\alpha]_D$ −76° (*c* 1.1 in $CHCl_3$)]; δ_C 56.5 (OCH_3), 64.0 (C-5), 73.1 (OCH_2Ar), 74.3 (C-2), 76.5 (C-3), 78.3 (C-4), 105.3 (C-1), 128.1, 128.4, 128.9, and 139.9 (Ar); δ_H 3.20–3.26 (2 H, m, $J_{5a,5e}$ = 11.6 Hz, $J_{5a,4}$ = 9.3 Hz, H-2 and H-5a), 3.41 (3 H, s, OCH_3), 3.44 (1 H, dt, H-4), 3.57 (1 H, dt, $J_{3,OH}$ = 4.1 Hz, $J_{3,2} + J_{3,4}$ = 16.9 Hz, H-3), 3.94 (1 H, dd, $J_{5e,4}$ = 5.0 Hz, H-5e), 4.15 (1 H, d, $J_{1,2}$ = 7.2 Hz, H-1), 4.29 (0.8 H, d, $J_{OH,2}$ = 4.5 Hz, 2-OH), 4.78 (0.8 H, d, $J_{OH,3}$ = 4.1 Hz, 3-OH), 4.68 and 4.78 (2 × 1 H, d's, J_{gem} = 12.0 Hz, OCH_2Ar), 7.24–7.39 (5 H, m, Ar).

Methyl 4-*O*-Benzoyl-β-D-xylopyranoside (5). Methyl β-D-xylopyranoside (2.021 g, 12.3 mmol) and dibutyltin oxide (3.086 g, 12.4 mmol) were refluxed in benzene (60 mL) followed by the addition of benzoyl chloride (1.45 mL). Standard processing and subsequent silica gel chromatography (1:1 $CHCl_3$–EtOAc) gave 5 (3.066 g, 92.8%) which crystallized from EtOAc–petroleum ether: mp 122.5–123.5 °C; $[\alpha]_D$ −92.3° (*c* 1.26 in CH_2Cl_2) (lit.[26] mp 114.5–115.5 °C; $[\alpha]_D$ −92°); δ_C 56.7 (OCH_3), 63.1 (C-5), 73.3 (C-4), 74.4 (C-3), 74.6 (C-2), 105.4 (C-1), 129.2, 130.3, 130.8, and 133.9 (Ar), 166.3 (C=O); δ_H 3.36–3.41 (1 H, m, H-2), 3.42 (1 H, dd, $J_{5a,4}$ = 9.7 Hz, $J_{5a,5e}$ = 11.4 Hz, H-5a), 3.46 (3 H, s, OCH_3), 3.84 (1 H, dt, $J_{3,OH}$ = 4.5 Hz, $J_{3,2} + J_{3,4}$ = 17.9 Hz, H-3), 4.10 (1 H, dd, $J_{5e,4}$ = 5.4 Hz, H-5e), 4.27 (1 H, d, $J_{1,2}$ = 7.4 Hz, H-1), 4.59 (0.8 H, d, $J_{OH,2}$ = 3.9 Hz, 2-OH), 4.71 (0.8 H, d, 3-OH), 4.98 (1 H, dt, H-4). An identical product was obtained by the benzoylation of 3 followed by removal of the *O*-isopropylidene group.

Methyl 2-*O*-Benzoyl- (6) and Methyl 3-*O*-Benzoyl-4-*O*-benzyl-β-D-xylopyranosides (7). Crystalline 4 (3.04 g, 12 mmol) and dibutyltin oxide (3.03 g, 12.2 mmol) were refluxed in benzene (165 mL), and benzoyl chloride (1.4 mL, 12.1 mmol) was added. Reaction processing and silica gel chromatography (CCl_4–EtOAc (7:1 then 5:1)) afforded 6 (2.06 g, 48%) followed by 7 (1.45 g, 34%), which were crystallized from 95% EtOH and absolute EtOH, respectively. Compound 6: mp 140.0–141.5 °C; $[\alpha]_D$ −23.4° (*c* 0.914 in CH_2Cl_2); δ_C 56.4 (OCH_3), 64.3 (C-5), 73.4 (OCH_2Ar), 74.9 (C-3), 75.0 (C-2), 78.7 (C-4), 103.0 (C-1), 165.8 (C=O); δ_H 3.35 (1 H, dd, $J_{5a,4}$ = 9.8 Hz, $J_{5a,5e}$ = 11.5 Hz, H-5a), 3.37 (3 H, s, OCH_3), 3.61 (1 H, ddd, $J_{4,3}$ = 8.5 Hz, $J_{4,5e}$ = 5.2 Hz, H-4), 3.92 (1 H, dt, $J_{3,OH}$ = 5.3 Hz, $J_{3,2} + J_{3,4}$ = 17.7 Hz, H-3), 4.06 (1 H, dd, H-5e), 4.50 (1 H, d, $J_{1,2}$ = 7.6 Hz, H-1), 4.73 and 4.82 (2 × 1 H, d's, J_{gem} = 11.9 Hz, OCH_2Ar), 4.82 (0.8 H, d, 3-OH), 5.03 (1 H, dd, $J_{2,3}$ = 9.2 Hz, H-2). Anal. Calcd for $C_{20}H_{22}O_6$: C, 67.03; H, 6.19. Found: C, 67.14; H, 6.25.

Compound 7: mp 116.0–117.5 °C; $[\alpha]_D$ −67.4° (*c* 0.884 in CH_2Cl_2); δ_C 56.8 (OCH_3), 63.8 (C-5), 72.6 (C-2), 72.8 (OCH_2Ar), 76.3 (C-4), 77.1 (C-3), 105.5 (C-1), 166.1 (C=O); δ_H 3.41 (1 H, dd, $J_{5a,4}$ = 9.7 Hz, $J_{5a,5e}$ = 11.6 Hz, H-5a), 3.46 (3 H, s, OCH_3), 3.52 (1 H, m, H-2), 3.74 (1 H, dt, $J_{4,5e}$ = 5.1 Hz, $J_{4,3} + J_{4,5a}$ = 18.5 Hz, H-4), 4.12 (1 H, dd, H-5e), 4.33 (1 H, d, $J_{1,2}$ = 7.3 Hz, H-1), 4.51 (0.8 H, d, $J_{OH,2}$ = 5.1 Hz, 2-OH), 4.57 and 4.64 (2 × 1 H, d's, J_{gem} = 12.1 Hz, OCH_2Ar), 5.33 (1 H, t, $J_{3,2} + J_{3,4}$ = 18.0 Hz, H-3). Anal. Calcd for $C_{20}H_{22}O_6$: C, 67.03; H, 6.19. Found: C, 66.68; H, 6.27.

Methyl 3,4-Di-*O*-benzoyl-β-D-xylopyranoside (8). Methyl β-D-xylopyranoside (1.035 g, 6.31 mmol) and dibutyltin oxide (1.586 g, 6.37 mmol) were refluxed in benzene (60 mL), and benzoyl chloride (1.5 mL) was added. Processing provided a syrup which was purified by silica gel chromatography (20:1 CCl_4–acetone). The recovered material (2.33 g) could not be crystallized but was isolated from Et_2O/light petroleum ether as a gel which, upon drying, gave a white powder (1.88 g, 80%): $[\alpha]_D$ −114° (*c* 1.34 in acetone) (lit.[26] $[\alpha]_D$ −107°); δ_C 57.0 (OCH_3), 63.0 (C-5), 71.3 (C-4), 72.5 (C-2), 75.6 (C-3), 105.5 (C-1), 166.0 and 166.3 (C=O); δ_H 3.51 (3 H, s, OCH_3), 3.65 (1 H, dd, $J_{5a,4}$ = 9.8 Hz, $J_{5a,5e}$ = 11.5 Hz, H-5a), 3.70–3.76 (1 H, m, H-2), 4.26 (1 H, dd, $J_{5e,4}$ = 5.43 Hz, H-5e), 4.47 (1 H, d, $J_{1,2}$ = 7.3 Hz, H-1), 4.84 (0.8 H, d, $J_{OH,2}$ = 4.7 Hz, 2-OH), 5.22 (1 H, dt, $J_{4,3} + J_{4,5a}$ = 19.0 Hz, H-4), 5.58 (1 H, t, $J_{3,2} + J_{3,4}$ = 18.6 Hz, H-3).

2,3,5-Tri-*O*-benzoyl-α-L-arabinofuranosyl Chloride (10). Methyl 2,3,5-tri-*O*-benzoyl-α-L-arabinofuranoside[22] (2.50 g, 5.25 mmol) was dissolved in CH_2Cl_2 (50 mL) under an atmosphere of N_2, and dichloromethyl methyl ether (9.5 mL, 105 mmol) and $SnCl_4$ (3.9 mL, 1 M in CH_2Cl_2) were added with stirring. The

(25) Kováč, P.; Alföldi, J. *Chem. Zvesti* **1978**, *32*, 519.
(26) Petráková, E.; Schraml, J. *Collect. Czech. Chem. Commun.* **1983**, *48*, 877.

mixture was sealed with a nitrogen bubbler (to allow the escape of gas) and left stirring for 15 h at room temperature. A white precipitate formed immediately upon the addition of the tin chloride, which dissolved over the course of 4 h. The resulting amber solution was poured into an ice–water solution, with stirring, and both phases were transferred into a separatory funnel. The organic phase was diluted with additional CH_2Cl_2 and the mixture shaken. The CH_2Cl_2 layer was washed three additional times with cold, saturated, aqueous $NaHCO_3$. Standard processing afforded a syrup which crystallized from CCl_4/light petroleum ether to afford **10** (2.117 g, 83.9%) as small spherulitic crystals: mp 115–118 °C; $[\alpha]_D$ −28° (*c* 0.99 in acetone); δ_C 63.6 (C-5), 77.5 (C-3), 84.7 (C-4), 86.0 (C-2), 97.0 (C-1), 165.7, 166.1 and 166.3 (C=O); δ_H 4.85 (1 H, dd, $J_{5a,4}$ = 4.9 Hz, $J_{5a,5b}$ = 12.3 Hz, H-5a), 4.96 (1 H, dd, $J_{5b,4}$ = 3.2 Hz, H-5b), 5.04 (1 H, bq, J = 4.8, 7.9 Hz, H-4), 5.82 (1 H, bd, $J_{3,4}$ = 4.6 Hz, H-3), 5.90 (1 H, bs, H-2), 6.68 (1 H, s, H-1). Anal. Calcd for $C_{26}H_{21}O_7Cl$: C, 64.94; H, 4.40. Found: C, 65.15; H, 4.38.

Allyl β-D-Xylopyranoside (11). 2,3,4-Tri-*O*-acetyl-α-D-xylopyranosyl bromide[27] (13.29 g, 39.2 mmol) was dissolved in allyl alcohol (100 mL), and $Hg(CN)_2$ (10.4 g, 41.2 mmol) was added. The mixture was stirred for 2 days during which time a white precipitate formed. The precipitate was filtered off and the filtrate evaporated (50 °C) to a syrup, which was diluted with CH_2Cl_2 and washed with aqueous NaCl (2×). Processing of the organic layer and subsequent crystallization from absolute EtOH/light petroleum ether afforded allyl 2,3,4-tri-*O*-acetyl-β-D-xylopyranoside (**11a**) as needles (9.50 g, 77%): δ_C 70.1 ($OCH_2CH{=}CH_2$), 100.8 (C-1), 116.8 ($OCH_2CH{=}CH_2$), 135.1 ($OCH_2CH{=}CH_2$); δ_H 4.65 (1 H, d, $J_{1,2}$ = 7.2 Hz, H-1). Deacetylation was accomplished by the treatment of the triacetate (9.13 g, 28.9 mmol) with NaOMe (50 mg) in MeOH (100 mL) for 4 h. Neutralization with strongly acidic ion-exchange resin and standard processing afforded a syrup which crystallized from Et_2O giving **11** as long needles (4.58 g, 84%): mp 75.5–77.5 °C; $[\alpha]_D$ −63° (*c* 1.5 in acetone); δ_C 66.0 (C-5), 70.1 ($OCH_2CH{=}CH_2$), 70.4 (C-4), 73.9 (C-2), 77.0 (C-3), 103.4 (C-1), 116.8 ($OCH_2CH{=}CH_2$), 135.5 ($OCH_2CH{=}CH_2$); δ_H 3.19 (1 H, dd, $J_{5a,4}$ = 9.8 Hz, $J_{5a,5e}$ = 11.4 Hz, H-5a), 3.25 1 H, dd, $J_{2,1}$ = 7.3 Hz, $J_{2,3}$ = 8.7 Hz, H-2), 3.40 (1 H, t, $J_{3,2}$ + $J_{3,4}$ = 17.3 Hz, H-3), 3.54 (1 H, m, H-4), 3.84 (1 H, dd, $J_{5e,4}$ = 5.2 Hz, H-5e), 4.06 and 4.25 (2 × 1 H, m's, J_{gem} = 13.2 Hz, $OCH_2CH{=}CH_2$), 4.28 (1 H, d, $J_{1,2}$ = 7.3 Hz, H-1), 5.11 and 5.29 (2 × 1 H, m's, $OCH_2CH{=}CH_2$), 5.91 (1 H, m, $OCH_2CH{=}CH_2$).

Allyl 4-*O*-Benzoyl-β-D-xylopyranoside (12). Allyl β-D-xylopyranoside (511 mg, 2.69 mmol) and dibutyltin oxide (700 mg, 2.81 mmol) were refluxed in benzene (30 mL) followed by the addition of benzoyl chloride (325 μL). Processing and silica gel chromatography (9:1 $CHCl_3$–EtOAc) afforded a white foam (645 mg, 81.5%) which crystallized from CCl_4/light petroleum ether: mp 104–105 °C; $[\alpha]_D$ −84° (*c* 1.56 in $CHCl_3$); δ_C 63.0 (C-5), 70.1 ($OCH_2CH{=}CH_2$), 73.2 (C-4), 74.4 (C-3), 74.5 (C-2), 103.5 (C-1), 116.8 ($OCH_2CH{=}CH_2$), 133.9 ($OCH_2CH{=}CH_2$), 166.2 (C=O); δ_H 3.39–3.50 (2 H, m, $J_{5a,4}$ = 9.8 Hz, $J_{5a,5e}$ = 11.4 Hz, H-2 and H-5a), 3.87 (1 H, dt, $J_{3,OH}$ = 4.6 Hz, $J_{3,2}$ + $J_{3,4}$ = 18.0 Hz, H-3), 4.09–4.15 (2 H, m, $J_{5e,4}$ = 5.3 Hz, $OCH_2CH{=}CH_2$ and H-5e), 4.31 (1 H, m, J_{gem} = 13.2 Hz, $OCH_2CH{=}CH_2$), 4.42 (1 H, d, $J_{1,2}$ = 7.4 Hz, H-1), 4.64 (0.8 H, d, $J_{OH,2}$ = 4.2 Hz, 2-OH), 4.72 (0.8 H, d, $J_{OH,3}$ = 4.6 Hz, 3-OH), 5.01 (1 H, dt, $J_{4,5a}$ + $J_{4,3}$ = 18.9 Hz, H-4), 5.14 and 5.34 (2 × 1 H, m's, $OCH_2CH{=}CH_2$), 5.94 (1 H, ddd, J = 17.2, 10.7 and 5.4 Hz, $OCH_2CH{=}CH_2$). Anal. Calcd for $C_{15}H_{18}O_6$: C, 61.22; H, 6.16. Found: C, 60.94; H, 6.04.

Allyl 3,4-Di-*O*-benzoyl-β-D-xylopyranoside (13). Allyl β-D-xylopyranoside (1.04 g, 5.47 mmol) and dibutyltin oxide (1.42 g, 5.72 mmol) were refluxed in benzene (75 mL) followed by the addition of benzoyl chloride (1.3 mL, 11.2 mmol). Processing and silica gel chromatography (20:1 CCl_4–acetone) gave **13** as a syrup (1.94 g, 89.3%) which was crystallized from CCl_4/petroleum ether as needles: mp 91–92 °C; $[\alpha]_D$ −107° (*c* 1.9 in $CHCl_3$); δ_C 62.9 (C-5), 70.4 ($OCH_2CH{=}CH_2$), 71.2 (C-4), 72.4 (C-2), 75.4 (C-3), 103.6 (C-1), 116.9 ($OCH_2CH{=}CH_2$), 135.3 ($OCH_2CH{=}CH_2$), 166.0 and 166.2 (C=O); δ_H 3.67 (1 H, dd, $J_{5a,4}$ = 9.7 Hz, $J_{5a,5e}$ = 11.5 Hz, H-5a), 3.83 (1 H, ddd, $J_{2,OH}$ = 4.8 Hz, $J_{2,1}$ = 7.3 Hz, $J_{2,3}$ = 9.2 Hz, H-2), 4.18 and 4.38 (2 × 1 H, m's, J_{gem} = 13.2 Hz, $OCH_2CH{=}CH_2$) 4.29 (1 H, dd, $J_{5e,4}$ = 5.4 Hz, H-5e), 4.64 (1 H, d, H-1), 4.93 (0.8 H, d, 2-OH), 5.16 and 5.37 (2 × 1 H, m's, $OCH_2CH{=}CH_2$), 5.27 (1 H, dt, $J_{4,5a}$ + $J_{4,3}$ = 18.8 Hz, H-4), 5.64 (1 H, t, $J_{3,2}$ + $J_{3,4}$ = 18.4 Hz, H-3), 5.97 (1 H, ddd, $OCH_2CH{=}CH_2$). Anal. Calcd for $C_{22}H_{22}O_7$: C, 66.32; H, 5.57. Found: C, 65.97; H, 5.48.

Methyl 4-*O*-(4-*O*-Acetylferuloyl)-β-D-xylopyranoside (14). Methyl β-D-xylopyranoside (1.00 g, 6.10 mmol), dibutyltin oxide (1.55 g, 6.21 mmol), and benzene (50 mL) were refluxed in the usual way. The mixture was frozen in liquid nitrogen and placed under high vacuum. A white fluffy solid (2.38 g) was obtained and a portion (930 mg) dissolved in freshly distilled toluene (20 mL). Crystalline 4-*O*-acetylferuloyl chloride[19] (609 mg, 2.39 mmol) was added with stirring at room temperature, and the mixture was stirred for an additional 4 h. Standard processing and silica gel chromatography (9:1 $CHCl_3$–EtOAc) gave the 3,4-di-*O*-substituted material (212 mg, 15%). Further elution with $CHCl_3$–EtOAc (1:1) gave **14** as a white foam (530 mg, 59%). The total efficiency of acid chloride use was 88%: $[\alpha]_D$ −77° (*c* 0.85 in acetone); δ_C 20.4 (Ac), 56.4 (OCH_3), 56.7 (OCH_3), 63.2 (C-5), 72.8 (C-4), 74.6 and 74.8 (C-2 and C-3), 105.6 (C-1), 112.4 (C-1′), 118.8 (C-8′), 122.3 (C-6′), 124.1 (C-5′), 134.1 (C-1′), 142.7 (C-3′), 145.3 (C-7′), 152.7 (C-4′), 166.7 (C-9′), 168.8 (C=O); δ_H 2.24 (3 H, s, Ac), 3.30–3.36 (2 H, m, H-2 and H-5a), 3.43 (3 H, s, OCH_3), 3.71 (1 H, dt, $J_{3,OH}$ = 4.6 Hz, $J_{3,2}$ + $J_{3,4}$ = 17.9 Hz, H-3), 3.87 (3 H, s, OCH_3), 4.03 (1 H, dd, $J_{5e,5a}$ = 11.4 Hz, $J_{5e,4}$ = 5.3 Hz, H-5e), 4.21 (1 H, d, $J_{1,2}$ = 7.4 Hz, H-1), 4.47 (0.8 H, d, $J_{OH,2}$ = 4.5 Hz, 2-OH), 4.52 (0.8 H, d, $J_{OH,3}$ = 4.5 Hz, 3-OH), 4.84 (1 H, dt, $J_{4,5a}$ + $J_{4,3}$ = 18.7 Hz, H-4), 6.55 (1 H, d, $J_{8',7'}$ = 16.0 Hz, H-8′), 7.10 (1 H, d, $J_{5',6'}$ = 8.1 Hz, H-5′), 7.24 (1 H, dd, $J_{6',2'}$ = 1.7 Hz, H-6′), 7.43 (1 H, d, H-2′), 7.67 (1 H, d, H-7′). Anal. Calcd for $C_{18}H_{22}O_9$: C, 56.54; H, 5.80. Found: 56.66; H, 5.85.

Methyl 4-*O*-Benzoyl-3-*O*-(chloroacetyl)-β-D-xylopyranoside (15). Methyl β-D-xylopyranoside (1.005 g, 6.12 mmol) and dibutyltin oxide (1.553 g, 6.26 mmol) were refluxed in benzene (30 mL). The mixture was cooled to 22 °C, and benzoyl chloride (740 μL, 6.40 mmol) was added. The mixture was stirred for 20 min and chloroacetyl chloride (510 μL, 6.40 mmol) was added, which resulted in the immediate formation of a precipitate. The mixture was stirred for 1 additional h then diluted with benzene/light petroleum ether (1:1) and filtered. The solid was washed with petroleum ether and crystallized from hot 95% EtOH to afford **15** as long white needles (845 mg, 40%). Additional **15** (274 mg, 13%) was obtained by silica gel chromatography of the filtrate (19:1 $CHCl_3$–EtOAc to 1:1 $CHCl_3$–EtOAc) along with **8** (332 mg, 14.5%), methyl 3,4-di-*O*-(chloroacetyl)-β-D-xylopyranoside (22 mg, 1.1%), and **5** (347 mg, 21%). Total D-xylopyranoside recovery was 90.2%. Compound **15**: mp 158.5–160.0 °C; $[\alpha]_D$ −91° (*c* 1.12 in acetone); δ_C (DMSO-d_6) 41.1 (CH_2Cl), 56.3 (OCH_3), 61.7 (C-5), 70.2 (C-4), 70.7 (C-2), 76.0 (C-3), 104.0 (C-1), 165.1 and 167.1 (C=O); δ_H (DMSO-d_6) 3.38–3.46 (4 H, m, OCH_3 and H-2), 3.52 (1 H, dd, $J_{5a,4}$ = 10 Hz, $J_{5a,5e}$ = 11.3 Hz, H-5a), 4.09 (1 H, dd, $J_{5e,4}$ = 5.4 Hz, H-5e), 4.33 (2 H, s, CH_2Cl), 4.38 (1 H, d, $J_{1,2}$ = 7.5 Hz, H-1), 4.96 (1 H, dt, $J_{4,3}$ + $J_{4,5a}$ = 19.2 Hz, H-4), 5.25 (1 H, t, $J_{3,2}$ + $J_{3,4}$ = 18.8 Hz, H-3). Anal. Calcd for $C_{15}H_{16}O_7Cl$: C, 52.26; H, 4.97. Found: C, 52.56; H, 4.93.

Benzyl α-D-Xylopyranoside (17). D-Xylose (2.073 g, 13.8 mmol) was added to a freshly prepared solution hydrogen chloride in benzyl alcohol (20 mL, made by the addition of 400 μL of acetyl chloride), and the mixture was stirred for 24 h at 45 °C. Dilution of the reaction product with diethyl ether (30 mL) and then petroleum ether (40 mL) caused selective crystallization of **17** as needles overnight at room temperature. The crystals were isolated by filtration and washed with diethyl ether (1.063 g, 32%); mp 128–129.5 °C; $[\alpha]_D$ +139° (*c* 3.93 in H_2O) [lit.[28] mp 127–128.5 °C; $[\alpha]_D$ +139.2° (*c* 4 in H_2O)]; δ_C (D_2O-exchanged) 63.1 (C-5), 69.7 (OCH_2Ar), 71.1 (C-4), 73.4 (C-2), 75.2 (C-3), 99.4 (C-1); δ_H (D_2O-exchanged) 3.38 (1 H, dd, $J_{2,1}$ = 3.6 Hz, $J_{2,3}$ = 9.3 Hz, H-2), 3.47–3.58 (3 H, m, 4-H, H-5a and H-5e), 3.68 (1 H, t, $J_{3,2}$ + $J_{3,4}$ = 17.3 Hz, H-3), 4.50 and 4.73 (2 × 1 H, d's, J_{gem} = 12.1 Hz, OCH_2Ar), 4.83 (1 H, d, H-1), 7.25–7.42 (5 H, m, Ar).

Partial Benzoylation of 17. Crystalline **17** (404 mg, 1.68 mmol) and dibutyltin oxide (431 mg, 1.73 mmol) were refluxed in benzene (35 mL). The resulting mixture was cooled in an

(27) Schroeder, L. R.; Counts, K. M.; Haigh, F. C. *Carbohydr. Res.* **1974**, *37*, 368.

(28) Ballou, C. E.; Roseman, S.; Link, K. P. *J. Am. Chem. Soc.* **1951**, *73*, 1140.

ice–water bath, and benzoyl chloride (205 μL, 1.76 mmol) was added dropwise. Standard processing afforded a syrup which was submitted to silica gel chromatography (40 g silica packed with $CHCl_3$–EtOAc (19:1). Elution with $CHCl_3$–EtOAc (9:1, 500 mL) gave **21** (108 mg, 14.3%) followed by **19** (167 mg, 28.9%) and then **18** (252 mg, 43.5%). **Benzyl 2-*O*-benzoyl-α-D-xylopyranoside (18)** crystallized from absolute EtOH/petroleum ether as very long thin needles: mp 139–140 °C; $[\alpha]_D$ +155° (*c* 0.80 in acetone) [lit.[29] mp 140–141.5 °C, $[\alpha]_D$ +132° (*c* 0.71 in $CHCl_3$)]; δ_C 62.7 (C-5), 69.6 (OCH_2Ar), 71.4 (C-4), 72.4 (C-3), 75.1 (C-2), 96.5 (C-1), 166.5 (C=O); δ_H 3.64–3.78 (3 H, m, H-4, H-5a and H-5e), 4.08–4.14 (1 H, m, H-3), 4.38 (0.8 H, $J_{OH,4}$ = 5.2 Hz, 4-OH), 4.51 and 4.76 (2 × 1 H, d's, J_{gem} = 12.5 Hz, OCH_2Ar), 4.62 (0.8 H, d, $J_{OH,3}$ = 4.7 Hz, 3-OH), 4.90 (1 H, dd, $J_{2,1}$ = 3.7 Hz, $J_{2,3}$ = 9.9 Hz, H-2), 5.14 (1 H, d, H-1). **Benzoyl 4-*O*-benzoyl-α-D-xylopyranoside (19)** crystallized from absolute EtOH/petroleum ether as needles: mp 147–149.5 °C; $[\alpha]_D$ +72° (*c* 0.49 in acetone); δ_C 59.6 (C-5), 70.0 (OCH_2Ar), 72.1 (C-3), 73.5 (C-2 and C-4), 99.3 (C-1), 166.3 (C=O); δ_H 3.64 (1 H, ddd, $J_{2,1}$ = 3.6 Hz, $J_{2,OH}$ = 7.5 Hz, $J_{2,3}$ = 9.5 Hz, H-2), 3.72 (1 H, t, $J_{5a,4} + J_{5a,5e}$ = 20.4 Hz, H-5a), 3.86 (1 H, dd, $J_{5e,4}$ = 5.8 Hz, $J_{5e,5a}$ = 10.7 Hz, H-5e), 4.09 (0.8 H, d, 2-OH), 4.13 (1 H, dt, $J_{3,OH}$ = 4.4 Hz, $J_{3,2} + J_{3,4}$ = 18.6 Hz, H-3), 4.57 and 4.79 (2 × 1 H, d's, J_{gem} = 12.1 Hz, OCH_2Ar), 4.64 (0.8 H, d, 3-OH), 4.98 (1 H, d, H-1), 5.02 (1 H, ddd, $J_{4,3}$ = 9.3 Hz, $J_{4,5a}$ = 10.6 Hz, H-4). Anal. Calcd for $C_{19}H_{20}O_6$: C, 66.27; H, 5.85. Found: C, 65.80; H, 5.75.

Methyl 2,4-Di-*O*-benzoyl-α-D-xylopyranoside (20). Methyl α-D-xylopyranoside (5.048 g, 30.7 mmol), dibutyltin oxide (7.963 g, 32.0 mmol), and benzene (80 mL) were refluxed in standard fashion followed by the addition of benzoyl chloride (7.25 mL, 62.5 mmol). Processing provided a syrup which, upon treatment with boiling petroleum ether, furnished a white precipitate which was isolated by filtration. The solid was crystallized from absolute ethanol to furnish **20** as rhombic crystals (9.406 g, 82.1%): mp 158.0–160.0 °C; $[\alpha]_D$ +79° (*c* 2.14 in $CHCl_3$) [lit.[18b] mp 161–163 °C, $[\alpha]_D$ +62° (*c* 1.2 in $CHCl_3$)]; δ_C 55.6 (OCH_3), 59.1 (C-5), 69.3 (C-3), 73.3 (C-4), 74.9 (C-2), 98.2 (C-1), 166.2 and 166.4 (C=O); δ_H 3.40 (3 H, s, OCH_3), 3.72 (1 H, t, $J_{5a,4} + J_{5a,5e}$ = 21.4 Hz, H-5a), 3.92 (1 H, dd, $J_{5e,4}$ = 5.8 Hz, $J_{5e,5a}$ = 10.9 Hz, H-5e), 4.42 (1 H, dt, $J_{3,OH}$ = 5.2 Hz, $J_{3,2} + J_{3,4}$ = 18.2 Hz, H-3), 4.99–5.04 (2.8 H, m, 3-OH, H-2 and H-1), 5.14 (1 H, ddd, $J_{4,3}$ = 9.1 Hz, $J_{4,5a}$ = 10.5 Hz, H-4).

Benzyl 2,4-Di-*O*-benzoyl-α-D-xylopyranoside (21). Crystalline **17** (995 mg, 4.14 mmol) and dibutyltin oxide (1.084 g, 4.36 mmol) were refluxed in benzene (40 mL) followed by the addition of benzoyl chloride (985 μL, 8.49 mmol). Processing and silica gel chromatography ($CHCl_3$) gave a clear syrup which could not be crystallized (90% yield): $[\alpha]_D$ +80° (*c* 1.43 in $CHCl_3$) [lit.[29] $[\alpha]_D$ +79 °C (*c* 0.54 in $CHCl_3$)]; δ_C 59.5 (C-5), 69.3 (C-3), 70.0 (OCH_2Ar), 73.3 (C-4), 74.8 (C-2), 96.4 (C-1), 166.2 and 166.3 (C=O); δ_H 3.87 (1 H, t, $J_{5a,4} + J_{5a,5e}$ = 21.4 Hz, H-5a), 3.99 (1 H, dd, $J_{5e,4}$ = 5.8 Hz, $J_{5e,5a}$ = 10.9 Hz, H-5e), 4.52 (1 H, bt, $J_{3,2} + J_{3,4}$ = 18.9 Hz, H-3), 4.58 and 4.82 (2 × 1 H, d's, J_{gem} = 12.4 Hz, OCH_2Ar), 5.08 (1 H, dd, $J_{2,1}$ = 3.7 Hz, $J_{2,3}$ = 9.7 Hz, H-2), 5.20 (1 H, ddd, $J_{4,3}$ = 9.2 Hz, $J_{4,5a}$ = 10.5 Hz, H-4), 5.25 (1 H, d, H-1).

Benzyl (2,3,5-Tri-*O*-benzoyl-α-L-arabinofuranosyl)-(1→3)-2,4-di-*O*-benzoyl-α-D-xylopyranoside (22). Syrupy **21** (503.6 mg, 1.12 mmol), CH_2Cl_2 (35 mL), and powdered molecular sieves (900 mg) were stirred under an atmosphere of N_2. The solution was cooled (0 °C), and crystalline **7** (716 mg, 1.49 mmol) was added. After dissolution of **7** was complete, solid silver triflate (725 mg, 2.82 mmol) and collidine (323 mg, 2.66 mmol) were added in rapid succession. The reaction was complete within 15 min, after which the mixture was filtered through a bed of Celite. The filtrate was washed successively with aqueous $Na_2S_2O_3$, cold 3 N H_2SO_4, and water. Standard processing and silica gel chromatography (40 g silica in $CHCl_3$–light petroleum ether, (4:1)) afforded **22** as a white foam (916 mg, 91%): $[\alpha]_D$ +53° (*c* 1.8 in $CHCl_3$); δ_C 59.7 (X-5), 63.9 (A-5), 70.2 (OCH_2Ar), 70.7 (X-4), 74.4 (X-3), 74.9 (X-2), 78.2 (A-3), 82.2 (A-4), 83.0 (A-2), 96.3 (X-1), 107.4 (A-1); δ_H 3.96 (1 H, t, $J_{5a,5e} + J_{5a,4}$ = 21.7 Hz, X-5a), 4.05 (1 H, dd, $J_{5e,4}$ = 6.1 Hz, $J_{5e,5a}$ = 11.0 Hz, X-5e), 4.34 and 4.53 (2 × 1 H, dd's, $J_{5,4}$ = 4.3 and 3.7 Hz, J_{gem} = 11.6 Hz, A-5's), 4.40 (1 H, q, J = 4.1 Hz, A-4), 4.59 and 4.84 (2 × 1 H, d's, J_{gem} = 12.4 Hz, OCH_2Ar), 4.80 (1 H, t, $J_{3,2} + J_{3,4}$ = 18.3 Hz, X-3), 5.29–5.34 (2 H, m, X-1 and X-2), 5.40 (1 H, d, $J_{2,3}$ = 1.3 Hz, A-2), 5.45 (1 H, ddd, $J_{4,3}$ = 9.4 Hz, $J_{4,5a}$ = 10.5 Hz, X-4), 5.52 (1 H, bd, $J_{3,4}$ = 3.8 Hz, A-3), 5.75 (1 H, s, A-1). Anal. Calcd for $C_{52}H_{44}O_{14}$: C, 69.95; H, 4.97. Found: C, 70.07; H, 4.97.

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Registry No. **1**, 612-05-5; **2**, 137232-53-2; **3**, 118203-99-9; **4**, 69984-20-9; **5**, 83158-29-6; **6**, 137232-54-3; **7**, 137232-55-4; **8**, 83158-28-5; **10**, 42868-97-3; **11**, 73787-48-1; **11a**, 39102-79-9; **12**, 137232-56-5; **13**, 137232-57-6; **14**, 137232-58-7; **15**, 137232-59-8; **17**, 18403-12-8; **18**, 18403-20-8; **19**, 137232-60-1; **20**, 83158-21-8; **21**, 18403-18-4; **22**, 137232-61-2; dibutyltin oxide, 818-08-6; methyl 2,3,5-tri-*O*-benzoyl-α-L-arabinofuranoside, 42793-97-5; 2,3,4-tri-*O*-acetyl-α-D-xylopyranosyl bromide, 3068-31-3; 4-*O*-acetylferuloyl chloride, 50906-12-2; D-xylose, 58-86-6.

Supplementary Material Available: ^{13}C NMR spectra of compounds **2–8**, **10–15**, and **17–22** along with a brief note on the use of acetone-d_6 for acquiring routine NMR data (21 pages). Ordering information is given on any current masthead page.

(29) Sivakumaran, T.; Jones, J. K. N. *Can. J. Chem.* **1967**, *45*, 2493.