Carbohydrate Research 346 (2011) 534–539

Contents lists available at ScienceDirect

Carbohydrate Research

journal homepage: www.elsevier.com/locate/carres

$FeCl_3$ mediated arylidenation of carbohydrates

Nabamita Basu, Sajal K. Maity, Soumik Roy, Shuvendu Singha †, Rina Ghosh *

Department of Chemistry, Jadavpur University, Kolkata 700 032, India

ARTICLE INFO

Article history:
Received 20 November 2010
Received in revised form 31 December 2010
Accepted 6 January 2011
Available online 21 January 2011

Keywords:
$FeCl_3$
Benzylidenation
Arylidenation
Lewis acid
Catalyzed

ABSTRACT

Glycosides and thioglycosides based on monosaccharides in reaction with benzaldehyde dimethylacetal or *p*-methoxybenzaldehyde dimethyl acetal undergo $FeCl_3$-catalyzed (20 mol %) regioselective 4,6-O-arylidenation producing the corresponding acetals in high yields. $FeCl_3$ also mediates acetalation of glycosides and thioglycosides of cellobiose, maltose, and lactose affording the corresponding 4′,6′-*O*-benzylidene acetals, which were isolated after their acetylation in situ with acetic anhydride and pyridine. The combined yields (two steps) of these final products are also high (61–84%). The procedure is applicable to a wide variety of functional groups including –OBn.

1. Introduction

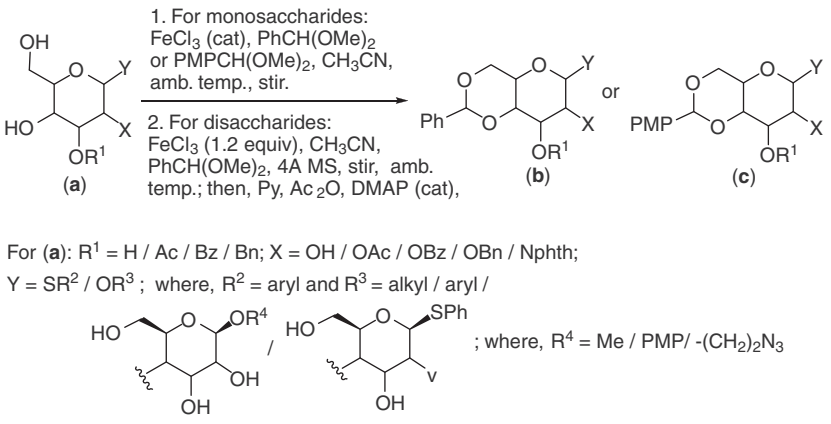
Protection and deprotection of functional groups are two important functional group transformations in synthetic carbohydrate chemistry.[1] In this field, benzylidenation is generally used to protect 1,2- and 1,3-diols, as such protections are stable under neutral and basic conditions. 4,6-O-Benzylidenated monosaccharides are of particular importance in the synthesis of complex carbohydrates[2] as these can be selectively transformed under oxidative conditions to the corresponding 6-bromo-4-*O*-benzoyl-6-deoxy sugars in reaction with NBS.[3] The acetals can also either be selectively deprotected under reductive conditions[4] to give the corresponding 4-O-benzylated or 6-O-benzylated product keeping the other hydroxyl group free. The resulting compounds can act as glycosyl acceptors during oligosaccharide synthesis. Several methods for the preparation of benzylidene acetals have been reported. Of these earlier methods that use benzaldehyde as the electrophile, most were catalyzed by $ZnCl_2$,[5] H_2SO_4,[6] or TsOH[7] and the like. Later benzaldehyde dimethyl acetal was proved to be a better reagent, and transacetalations were achieved with Brønsted acids (HBF_4,[8] CSA, and TsOH[9]), including silica gel supported ones ($NaHSO_4$–SiO_2[10] or H_2SO_4–SiO_2[11], or $HClO_4$–SiO_2[12]) or Lewis acid [$VO(OTf)_2$][13] or by other reagents like I_2.[14] $PhCHBr_2$ can also be used as an electrophile for benzylidenation under basic (pyridine) conditions.[15] Recently, in continuation of our work on carbohydrates,[16] in connection with some oligosaccharide synthesis, we were trying to prepare benzylidene acetals of some disaccharide substrates employing the established transacetalation methodologies, we could not obtain the corresponding benzylidene acetals in good yields. Thus, we were in search of suitable conditions for the above purpose. Recently, $FeCl_3$ has been used to mediate various organic transformations, like, iodination,[17a] Friedel–Crafts alkylation,[17b] addition of active methylene to styrene derivatives,[17c] intermolecular O-arylation,[17d] coupling of alkynes and alcohols,[17e] oxidative coupling of aromatic nuclei,[17f] 1,2-addition of aryl aldehyde with aryl boronic acid,[17g] synthesis of 3,3-diindolyl oxyindoles,[17h] synthesis of structurally diverse indenes,[17i] synthesis of 5-hydroxy-1*H*-pyrrol-2-(5*H*)-ones,[17j] acetylation of carbohydrates,[17k] α-glycosidation,[17l] and O-isopropylidenation of carbohydrates,[17m] among others. We observed that inexpensive and eco-friendly $FeCl_3$ could mediate arylidenation of sugars (mono- and disaccharides) in high yields; the results of these reactions are reported herein (Schemes 1 and 2, and Tables 1–3).

2. Results and discussion

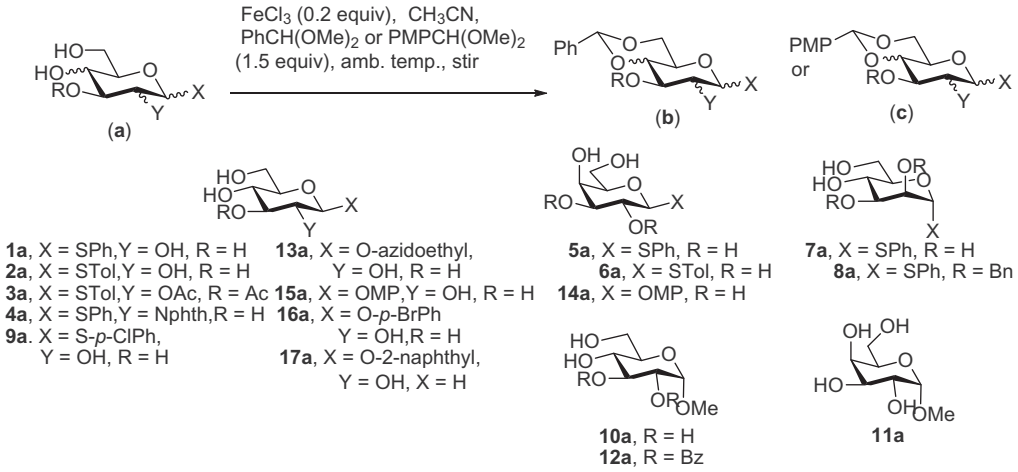
At the outset, phenyl 1-thio-β-D-glucoside (**1a**) was chosen as the substrate for the standardization of reaction conditions for its reaction with benzaldehyde dimethylacetal in the presence of $FeCl_3$ using CH_3CN or DMF as solvent. Best results were obtained from the reaction of **1a** (1.0 equiv) and benzaldehyde dimethyl acetal (1.5 equiv) in the presence of 20 mol % $FeCl_3$ in CH_3CN at ambient temperatures, which produced the corresponding 4,6-*O*-benzylidene acetal (**1b**[16g]) in excellent yield (92%, entry 1, Table 1). Under similar reaction conditions, other phenyl 1-thioglycosides of 2-NPhth-β-D-Glc, -β-D-Gal and -α-D-Man furnished the corresponding 4,6-*O*-benzylidene derivatives (**4b**,[16i] **5b**[16g] and **7b**[16h]) in high

* Corresponding author. Tel.: +91 033 24146666x2504; fax: +91 033 24146266.
E-mail addresses: ghoshrina@yahoo.com, ghosh_rina@hotmail.com (R. Ghosh).
† In part.

0008-6215/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.carres.2011.01.003



Scheme 1. $FeCl_3$ mediated O-arylidenation of carbohydrates.



Scheme 2. $FeCl_3$-mediated O-arylidenation of monosaccharides.

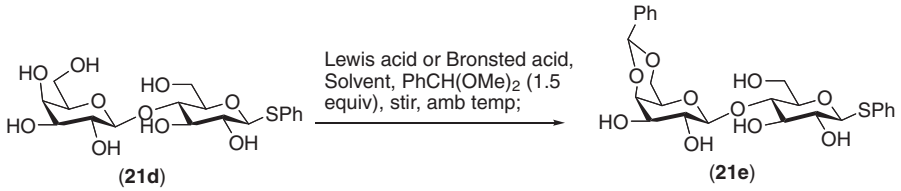
Table 1
$FeCl_3$-catalyzed arylidenation of monosaccharide substrates

#	Product	Time (h)	Yield[a] (%)	#	Product	Time (h)	Yield[a] (%)	#	Product	Time (h)	Yield[a] (%)
1	**1b**	2.5	92	8	**8b**	2.5	88	15	**15b**	2.5	88
2[b]	**2b**	2.5	86 (87)	9	**9b**	2.5	88	16	**16b**	2.5	83
3	**3b**	2.5	85	10	**10b**	3.5	86	17	**17b**	2.0	90
4	**4b**	2.5	81	11	**11b**	3.5	85	18	**1c**	2.5	88
5	**5b**	2.5	86	12	**12b**	3.5	85	19	**2c**	2.5	85
6	**6b**	3.0	85	13	**13b**	2.5	79	20	**5c**	2.5	87
7	**7b**	2.0	76	14	**14b**	2.5	65	21	**6c**	2.5	85

[a] Isolated yield.
[b] Data in parenthesis represent the yield based on a 1-g scale.

yields (76–86%, entries 4, 5 and 7, respectively, Table 1). It may be mentioned here that in some of the reported procedures for sugar benzylidenation, the yield of the 4,6-*O*-benzylidene acetal of phenyl 1-thio-α-D-mannopyranoside is low to moderate because of formation of the corresponding 2,3:4,6-di-*O*-benzylidene product in appreciable amounts.[9,10,18] Under the present conditions only trace amounts of the product dibenzylidene were formed, and the 4,6-*O*-benzylidene acetal (**7b**) was obtained in 76% yield (entry 7). Efficient 4,6-O-benzylidenation was also possible from *p*-tolyl 1-thio-D-glycosides (**2b**,[10] **3b**[11], and **6b**,[13] entries 2, 3 and 6) and *p*-chlorophenyl 1-thio-β-D-glucoside (entry 9), which afforded their respective products in high yields (85–88%). The efficiency of the present procedure was further established under a scale-up reaction of **2a** (1 g), benzaldehyde dimethyl acetal, and 20 mol % of $FeCl_3$, which gave **2b** in 87% yield (entry 2 in parenthesis, Table 1). Except for methyl α-D-mannopyranoside (not shown), which was reluctant, probably due to its poor solubility and low reactivity, to undergo reaction under the present conditions, other methyl glycopyranosides (entries 10–12) and β-azidoethyl glucoside (entry 13) afforded the corresponding desired products (**10b**,[14b] **11b**[13] **12b**[10] and **13b**[19]) in very good yields. *p*-Methoxyphenyl, *p*-bromophenyl, and 2-naphthyl glycosides are also good substrates for affording their respective 4,6-*O*-benzylidene acetals (**14b**,[14b] **15b**,[20] **16b**, **17b**[21]) in high yields (entries 14–17). The present $FeCl_3$-catalyzed acetalation protocol was also applied to effect the efficient 4,6-*p*-methoxybenzylidenation of *S*-phenyl and *S*-tolyl

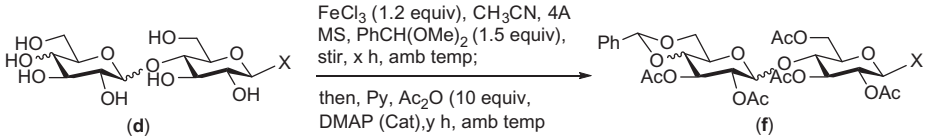
Table 2
Comparison of benzylidenation under different conditions of a disaccharide substrate

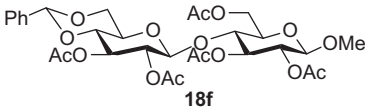
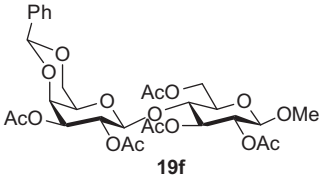
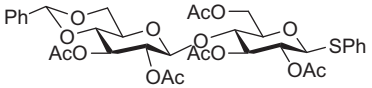
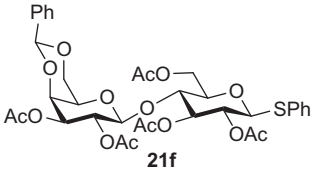
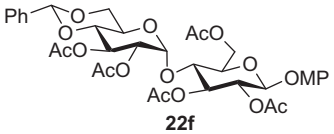
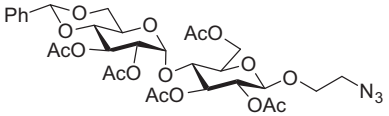


Entry	Catalyst/solvent	Time	Yield[a] (%)
1	$NaHSO_4$–SiO_2/CH_3CN[10]	1 d (incomplete)	42
2	I_2 (40 mol %)/CH_3CN[14]	1 d (incomplete)	37
3	*p*-TSA (20 mol %)/DMF[9]	3 d (complete)	81
4	$FeCl_3$ (20 mol %)/CH_3CN	1 d (incomplete)	40
5	$FeCl_3$ (1.2 equiv) + 4 Å Mol. Sieves/CH_3CN	2 h (complete)	86

[a] Isolated chromatographed (SiO_2) yields.

Table 3
$FeCl_3$-mediated benzylidenation of disaccharide substrates



Entry	Product	Time ($x + y$) (h)	Yield[a] (%)
1	 **18f**	(2.5 + 3.0)	67
2	 **19f**	(2.5 + 3.0)	72
3	 **20f**	(2.0 + 3.0)	61
4	 **21f**	(2.0 + 3.0)	84
5	 **22f**	(3.0 + 3.0)	67
6	 **23f**	(2.5 + 3.0)	69

[a] Isolated chromatographed combined yield (two steps).

glucosides (entries 18 and 19) and the corresponding galactosides (entries 20 and 21) using *p*-methoxybenzaldehyde dimethyl acetal as the electrophile, which proceeded well to furnish the corresponding 4,6-*O*-acetals (**1c**,[16g] **2c**,[13] **5c**[16g] and **6c**[13]) in high yields

(85–88%). The above conversions establish the applicability of the present protocol toward a wide variety of functions like O-alkyl/aryl glycosides, thioglycosides, benzoyl, acetate, phthalimido, azides, and benzyl groups. The regioselectivity of the present acetalation is excellent, as only the corresponding 4,6-O-benzylidene product is obtained in the D-Glc or D-Gal systems. It is also worthwhile to note here that, although $FeCl_3$ (3–24 equiv) is used for effecting debenzylation of sugars,[22] we did not observe any debenzylation using 20 mol % $FeCl_3$ during the course of benzylidenation reaction. Moreover, unlike that in $FeCl_3$-mediated debenzylation,[22] anomerisation[22b] of glycosides could not be observed. Since MeOH is a by-product of the benzylidenation using $PhCH(OMe)_2$, in situ generation of HCl by methanolysis of $FeCl_3$ cannot be ruled out. To explore if there is any role of this HCl for benzylidene acetal formation, **2a** was treated with 20 mol % HCl–CH_3CN and $PhCH(OMe)_2$, which generated the corresponding acetal (**2b**), but in lower yield; the reaction also took a longer time for completion compared to that based on $FeCl_3$. A slower reaction rate was also observed from a reaction of **2a** with $PhCH(OMe)_2$ in the presence of 20 mol % $FeCl_3$ and 2,4,6-tri-*tert*-butylpyrimidine (TTBP) compared to that done in the absence of the hindered base (TTBP). Thus, a dual Lewis ($FeCl_3$) and Brønsted (HCl) acid catalysis is probably operative under the present benzylidenation conditions.

The $FeCl_3$-mediated benzylidenation of a monosaccharide-glycoside was further extended for conversion of some disaccharide glycosides to their corresponding 4′,6′-*O*-benzylidene acetals. It may be mentioned here that maltose, lactose, and cellobiose are common disaccharide units of many biologically important glycoconjugates and polysaccharides in which chain extension of these units occurs via their C-4′ or C-6′ hydroxyl groups.[23] Thus these readily available disaccharides, through the formation of respective 4′,6′-*O*-benzylidene acetals, are convertible to their corresponding glycosyl donors or acceptors for the synthesis of those glycoconjugates or polysaccharides. Although, some of the reported methods (based on pTSA, $NaHSO_4$–SiO_2 or I_2) of sugar 4,6-*O*-benzylidenation work quite well in monosaccharide substrates affording the corresponding acetals in high yields,[9,10,14] but when we applied these standard reported protocols to the selected disaccharide substrate, for example, **21d** for its conversion to the corresponding 4′,6′-*O*-benzylidene acetal, the results were not satisfactory for the latter two reagents (entries 1 and 2, Table 2). On the other hand, *p*-TSA furnished a good yield of product (**21e**, 81%, entry 3), and the reaction required 3 days for completion. Use of 20 mol % $FeCl_3$ also produced the desired product (**21e**) in moderate yield (40%, entry 4, Table 2), probably because of the presence of a larger number of hydroxyl functions in the disaccharide system. Modification of the above $FeCl_3$-based conditions was thus necessary for the benzylidenation of disaccharide substrates. Interestingly, increasing the load of $FeCl_3$ to 1.2 equiv and performing the reaction in the presence of 4 Å molecular sieves dramatically improved the yield of disaccharide 4′,6′-O-benzylidene acetal **21e** (86%, entry 5, Table 2); the reaction was expeditious too. Following these conditions, several glycosides and thioglycosides of maltose, lactose, and cellobiose were next benzylidenated to afford their corresponding 4′,6′-*O*-benzylidenated products, which were isolated as acetates after their *in situ* one-pot acetylation using pyridine and acetic anhydride[‡] in the reaction mixture followed by chromatographic purification on an SiO_2-column. High combined yields (two steps) of the final products (**18f**–**23f**, 61–84%, entries 1–6, Table 3) indicate that the yields for each of the individual steps are quite high. It is to be noted here that **20f**[24] and **21f**[24] can be used directly as glycosyl donors, and **18f**,[25] **19f**[26], and **22f** are selectively convertible under reductive conditions to supply a desired glycosyl acceptor.

[‡] It may be mentioned here that acetylation with acetic anhydride at this stage in the absence of base (pyridine) required additional $FeCl_3$ (~1 equiv), which afforded the arylidenated–acetylated product along with some degraded products (probably due to acetolysis in the presence of excess $FeCl_3$), decreasing the yield of the desired product.

3. Conclusions

In summary, we have established that $FeCl_3$ mediates the O-arylidenation of monosaccharide and disaccharide glycosides affording the corresponding 4,6-O-arylidenated products in high yields. The advantages of the present procedure are its regioselectivity, generally high yields of products (under preparative scale too; moreover, if required, the benzylidene acetals can be converted in onepot to the corresponding acetates), and the use of inexpensive, eco-friendly, and readily available $FeCl_3$. It does not cause any bond cleavage or anomerization of glycosides or thioglycosides; moreover, it is also amenable to a wide variety of functional groups. The –OBn group is not deprotected under the reaction conditions.

4. Experimental

4.1. General experimental methods

Melting points are uncorrected. NMR spectra were recorded on a Bruker DPX 300 NMR spectrometer operating at 300 MHz and 75 MHz for ^1H and ^{13}C NMR spectra, respectively, in $CDCl_3$. HRMS data were recorded on a Q-TOF-Micro mass spectrometer by the electrospray-ionization method. Specific rotations were measured on a Jasco J-815 spectrometer.

4.2. General procedure for arylidenation of monosaccharides

To a solution of unprotected monosaccharide-glycosides (0.5 mmol) and benzaldehyde dimethyl acetal or *p*-methoxybenzaldehyde dimethyl acetal (0.75 mmol) in dry CH_3CN (2 mL), 20 mol % anhyd $FeCl_3$ was added with stirring at ambient temperature. After completion of reaction (indicated by TLC) the solvent was evaporated under reduced pressure. In most cases a solid mass was obtained, which was washed with minimum volume of cold water until it was acid free. Then it was dried and washed with chilled 5% EtOAc–petroleum ether to remove excess benzaldehyde dimethyl acetal. The dry, solid product was dissolved in CH_2Cl_2, and filtered, and the filtrate was evaporated to afford the product. Although the products obtained were pure enough, these were crystallized from distilled EtOH or EtOAc–petroleum ether before recording of the NMR data. In some cases (for products **3b**,[11] **4b**,[16i] **8b**,[16h] **10b**,[14b] **11b**[13], and **12b**,[10] Table 1), after evaporation of solvent from the reaction mixture, a syrupy material was obtained, which was dissolved in EtOAc. The EtOAc solution was washed with satd aq $NaHCO_3$ (1 × 5 mL) followed by cold water (2 × 5 mL). The organic layer was dried over dry Na_2SO_4 and concentrated under reduced pressure. The solid mass obtained (**10b** or **11b**) was washed with chilled 5% EtOAc–petroleum ether. For products **3b**, **4b**, **8b**, or **12b**, the syrupy mass was purified by column chromatography on silica gel (entries 3, 4, 8, 12, Table 1). For *p*-methoxybenzylidene acetals (**1c**,[16g] **2c**,[13] **5c**[16g] and **6c**[13]), after completion of the reaction the CH_3CN was evaporated under reduced pressure, and the residue was dissolved in EtOAc. This was washed with satd aq $NaHCO_3$ (1 × 5 mL) followed by cold water (2 × 5 mL). The organic layer was dried over anhyd Na_2SO_4 and then concentrated under reduced pressure. The syrupy residue was purified by filtration on an alumina column. The NMR spectral data of known compounds matched those reported.

4.3. Procedure for benzylidenation and acetylation of disaccharides

To a solution of unprotected disaccharides (0.2 mmol) and benzaldehyde dimethylacetal (0.3 mmol) in dry CH_3CN (3 mL) and 4 Å MS, anhyd $FeCl_3$ (0.24 mmol) was added, and the mixture was stirred at room temperature for 2–2.5 h. After completion of reaction (indicated by TLC), dry pyridine (1.5 mL), Ac_2O (2 mmol), and DMAP (10 mol %) were added. After complete acetylation, the reaction mixture was concentrated and diluted with CH_2Cl_2. It was washed with cold water (2 × 5 mL). The organic layer was dried over dry Na_2SO_4, and then concentrated under reduced pressure. It was purified by column chromatography on silica gel. The NMR spectra of known compounds (**18f**,[25] **19f**,[26] **20f**[24] and **21f**[24]) matched those reported.

4.4. Characteristic data of selected products

4.4.1. 4-Chlorophenyl 4,6-*O*-benzylidene-1-thio-β-D-glucopyranoside (9b)

Yield 88%; white crystals (EtOH); mp 156–158 °C; $[\alpha]_D^{25}$ −41.6 (*c* 1.59, $CHCl_3$); ^1H NMR ($CDCl_3$, 300 MHz): δ 7.48–7.45 (m, 4H), 7.37–7.29 (m, 5H), 5.51 (s, 1H), 4.57 (d, 1H, *J* = 9.7 Hz), 4.38–4.33 (m, 1H), 3.83–3.71 (m, 2H), 3.49–3.39 (m, 3H), 3.15 (br s, 1H), 2.94 (br s, 1H), ^{13}C NMR ($CDCl_3$, 75 MHz): δ 136.9, 135.0, 134.7, 129.8, 129.5, 129.4, 128.5, 126.4, 102.1, 88.4, 80.3, 74.7, 72.7, 70.7, 68.6; HRESIMS: calcd for $C_{19}H_{19}ClO_5SNa^+$ *m/z* 417.0540; found, *m/z* 417.0544.

4.4.2. 2′-Azidoethyl 4,6-*O*-benzylidene-β-D-glucopyranoside (13b)[19]

Yield 79%; white crystals (EtOH); mp 90–92 °C; $[\alpha]_D^{25}$ −57.4 (*c* 0.58, $CHCl_3$); ^1H NMR ($CDCl_3$, 300 MHz): δ 7.50–7.48 (m, 2H), 7.37–7.36 (m, 3H), 5.51 (s, 1H), 4.41 (d, 1H, *J* = 7.7 Hz), 4.32 (dd, 1H, *J* = 4.8, 10.4 Hz), 4.05–4.00 (m, 1H), 3.82–3.71 (m, 3H), 3.56–3.48 (m, 3H), 3.44–3.38 (m, 4H).

4.4.3. 4-Bromophenyl 4,6-*O*-benzylidene-β-D-glucopyranoside (16b)

Yield 83%; white crystals (EtOH); mp 182–184 °C; $[\alpha]_D^{25}$ −38.8 (*c* 0.89, $CHCl_3$); ^1H NMR ($CDCl_3$, 300 MHz): δ 7.51–7.48 (m, 2H), 7.42–7.36 (m, 5H), 6.95–6.92 (d, 2H, *J* = 8.9 Hz), 5.53 (s, 1H), 4.95 (d, 1H, *J* = 7.6 Hz), 4.35 (dd, 1H, *J* = 4.7, 10.6 Hz), 3.91–3.74 (m, 3H), 3.64–3.50 (m, 2H), 3.16 (s, 1H), 3.07 (d, 1H, *J* = 1.9 Hz), ^{13}C NMR (75 MHz, $CDCl_3$): δ 155.9, 136.8, 132.5, 129.4, 128.4, 126.3, 118.8, 115.8, 102.0, 101.2, 80.2, 74.2, 73.2, 68.5, 66.6; HRESIMS: calcd for $C_{19}H_{19}BrO_6Na^+$ *m/z* 445.0263; found, *m/z* 445.0267.

4.4.4. Methyl 2,3-di-*O*-acetyl-4,6-*O*-benzylidene-β-D-galactopyranosyl-(1→4)-2,4,6-tri-*O*-acetyl-1-thio-β-D-glucopyranoside (19f)[26]

Yield 72%; white crystals (EtOH); mp 220–222 °C; $[\alpha]_D^{25}$ +36.5 (*c* 0.1.46, $CHCl_3$).

4.4.5. Phenyl 2,3-di-*O*-acetyl-4,6-*O*-benzylidene-β-D-glucopyranosyl-(1→4)-2,4,6-tri-*O*-acetyl-1-thio-β-D-glucopyranoside (20f)[24]

Yield 61%; white crystals (EtOH); mp 264–266 °C, lit.[24] mp 267 ± 0.1 °C; $[\alpha]_D^{25}$ −42.5 (*c* 0.50, $CHCl_3$), lit.[24] $[\alpha]_D$ −45.3 (*c* 0.83, $CHCl_3$).

4.4.6. Phenyl 2,3-di-*O*-acetyl-4,6-*O*-benzylidene-β-D-galactopyranosyl-(1→4)-2,4,6-tri-*O*-acetyl-1-thio-β-D-glucopyranoside (21f)[24]

Yield 84%; white crystals (EtOH); mp 254–256 °C, lit.[24] mp 255 ± 0.25 °C; $[\alpha]_D^{25}$ +23 (*c* 0.50, $CHCl_3$), lit.[24] $[\alpha]_D$ +24.4 (*c* 0.70, $CHCl_3$).

4.4.7. 4-Methoxyphenyl 2,3-di-*O*-acetyl-4,6-*O*-benzylidene-α-D-glucopyranosyl-(1→4)-2,4,6-tri-*O*-acetyl-β-D-glucopyranoside (22f)

Yield 67% (two steps); white crystals (EtOH); mp 182–184 °C; $[\alpha]_D^{25}$ +24.5 (*c* 0.49, $CHCl_3$); ^1H NMR ($CDCl_3$, 300 MHz): δ 7.44–7.40 (m, 2H), 7.36–7.33 (m, 3H), 6.95–6.90 (m, 2H), 6.84–6.80 (m, 2H), 5.50–5.43 (m, 2H), 5.38 (d, 1H, *J* = 4.1 Hz), 5.31 (t, 1H, *J* = 8.8 Hz), 5.06 (t, 1H, *J* = 7.7 Hz), 4.97 (d, 1H, *J* = 7.7 Hz), 4.89 (dd, 1H, *J* = 4.2, 10.2 Hz), 4.54 (dd, 1H, *J* = 2.7, 12.1 Hz), 4.32–4.24 (m, 2H), 4.08 (t, 1H, *J* = 9.2 Hz), 3.91–3.80 (m, 2H), 3.77 (s, 3H), 3.74 (s, 1H), 3.70–3.60 (m, 1H), 2.08, 2.06, 2.05, 2.04, 2.01 (5 × s, 15H), ^{13}C NMR ($CDCl_3$, 75 MHz): δ 170.9, 170.4, 170.3, 169.9, 155.9, 150.9, 136.8, 129.2, 128.3, 126.3, 119.0, 114.7, 101.7, 99.9, 96.7, 78.9, 77.4, 75.6, 73.0, 72.4, 72.3, 71.0, 68.6, 63.9, 62.7, 55.8, 21.1, 20.9, 20.8, 20.7; HRESIMS: calcd for $C_{36}H_{42}O_{17}Na^+$ *m/z* 769.2320; found, *m/z* 769.2324.

4.4.8. 2′-Azidoethyl 2,3-di-*O*-acetyl-4,6-*O*-benzylidene-α-D-glucopyranosyl-(1→4)-2,4,6-tri-*O*-acetyl-β-D-glucopyranoside (23f)

Yield 69% (two steps); white crystals (EtOH); mp 186–188 °C; $[\alpha]_D^{25}$ +2.0 (*c* 2.25, $CHCl_3$); ^1H NMR ($CDCl_3$, 300 MHz): δ 7.42–7.34 (m, 5H), 5.48–5.42 (m, 2H), 5.36 (d, 1H, *J* = 3.8 Hz), 5.26 (t, 1H, *J* = 9.0 Hz), 4.90–4.82 (m, 2H), 4.61–4.57 (m, 2H), 4.26–4.22 (m, 2H), 4.06–3.98 (m, 2H), 3.89–3.81 (m, 1H), 3.76–3.59 (m, 4H), 3.51–3.44 (m, 1H), 3.26–3.22 (m,1H), 2.11, 2.05, 2.04, 2.02, 2.01 (5 × s, 15H), ^{13}C NMR ($CDCl_3$, 75 MHz): δ 170.8, 170.3, 170.2, 169.8, 169.7, 136.7, 129.1, 128.2, 126.2, 101.6, 100.2, 96.5, 78.8, 75.4, 72.6, 72.3, 72.0, 70.8, 69.2, 68.7, 68.5, 63.7, 62.3, 50.5, 20.9, 20.8 (2), 20.7, 20.6; HRESIMS: calcd for $C_{31}H_{39}N_3O_{16}Na^+$ *m/z* 732.2228; found, *m/z* 732.2229.

Acknowledgments

The authors are grateful to CSIR, New Delhi, India for providing a fellowship (JRF) to N.B. and for funding the project (No. 01/2382/10/EMR-II) to R.G. Support from FIST-DST, India to the Department of Chemistry, Jadavpur University, Kolkata is also acknowledged.

References

1. Greene, T. W.; Wuts, P. G. M. *Protective Groups in Organic Synthesis*, 3rd. ed.; John Wiley & Sons: New York, 1999.
2. (a)*Carbohydrates in Chemistry and Biology*; Ernst, B., Hart, G. W., Sinaÿ, P., Eds.; Wiley-VCH: Weinheim, 2000; Vol. 1, (b) Garegg, P. J. In *Preparative Carbohydrate Chemistry*; Hanessian, S., Ed.; Marcel Decker: New York, 1997; Chapter 3.
3. Gelas, J. *Adv. Carbohydr. Chem. Biochem.* **1981**, *39*, 71–156.
4. (a) Garegg, P. J. *Pure Appl. Chem.* **1984**, *56*, 845–858; (b) Shie, C.-R.; Tzeng, Z.-H.; Kulkarni, S. S.; Uang, B.-J.; Hsu, C.-Y.; Hung, S.-C. *Angew. Chem., Int. Ed.* **2005**, *44*, 1665–1668; (c) Panchadhayee, R.; Misra, A. K. *Synlett* **2010**, 1193–1196.
5. Fletcher, H. G. *Methods Carbohydr. Chem.* **1963**, *2*, 307–308.
6. Carman, R. M.; Kibby, J. J. *Aust. J. Chem.* **1976**, *29*, 1761–1767.
7. McGowan, D. A.; Berchtold, G. A. *J. Am. Chem. Soc.* **1982**, *104*, 7036–7041.
8. (a) Albert, R.; Das, K.; Pleschko, R.; Stütz, A. E. *Carbohydr. Res.* **1985**, *137*, 282–290; (b) Yamanoi, T.; Akiyama, T.; Ishida, E.; Abe, H.; Amemiya, M.; Inazu, T. *Chem. Lett.* **1989**, 335–337; (c) Morimoto, Y.; Mikami, A.; Kuwabe, S.-L.; Shirahama, H. *Tetrahedron Lett.* **1991**, *32*, 2909–2912.
9. Boulineau, F. P.; Wei, A. *Carbohydr. Res.* **2001**, *334*, 271–279.
10. Niu, Y.; Wang, N.; Cao, X.; Ye, X.-S. *Synlett* **2007**, 2116–2120.
11. Mukhopadhyay, B. *Tetrahedron Lett.* **2006**, *47*, 4337–4341.
12. Mukhopadhyay, B.; Russel, D. A.; Field, R. A. *Carbohydr. Res.* **2005**, *340*, 1075–1080.
13. Chen, C.-T.; Weng, S.-S.; Kao, J.-Q.; Lin, C.-C.; Jan, M.-D. *Org. Lett.* **2005**, *7*, 3343–3346.
14. (a) Kartha, K. P. R. *Tetrahedron Lett.* **1986**, *27*, 3415–3416; (b) Panchadhayee, R.; Misra, A. K. *J. Carbohydr. Chem.* **2008**, *27*, 148–155; (c) Jones, R. A.; Davidson, R.; Tran, A. T.; Smith, N.; Galan, M. C. *Carbohydr. Res.* **2010**, *345*, 1842–1845.
15. (a) Garegg, P. J.; Swahn, C.-G. *Methods Carbohydr. Chem.* **1980**, *8*, 317–319; (b) Russel, R. N.; Weigel, T. M.; Han, O.; Liu, H.-W. *Carbohydr. Res.* **1990**, *201*, 95–114.
16. (a) Ghosh, R.; De, D.; Shown, B.; Maiti, S. B. *Carbohydr. Res.* **1999**, *321*, 1–3; (b) Ghosh, R.; Chakraborty, A.; Maiti, D. K. *Synth. Commun.* **2003**, *33*, 1623–1632;

(c) Ghosh, R.; Chakraborty, A.; Maiti, S. *ARKIVOC* **2004**, *xiv*, 1–9; (d) Ghosh, R.; Chakraborty, A.; Maiti, D. K.; Puranik, V. G. *Tetrahedron Lett.* **2005**, *46*, 8047–8051; (e) Ghosh, R.; Chakraborty, A.; Maiti, D. K.; Puranik, V. G. *Org. Lett.* **2006**, *8*, 1061–1064; (f) Dassarma, M.; Ghosh, R.; Patra, A.; Chowdhury, R.; Chaudhuri, K.; Hazra, B. *Org. Biomol. Chem.* **2007**, *5*, 3115–3125; (g) Roy, S.; Chakraborty, A.; Ghosh, R. *Carbohydr. Res.* **2008**, *343*, 2523–2529; (h) Maity, S. K.; Maiti, S.; Patra, A.; Ghosh, R. *Tetrahedron Lett.* **2008**, *49*, 5847–5849; (i) Maity, S. K.; Patra, A.; Ghosh, R. *Tetrahedron* **2010**, *66*, 2809–2814; (j) Roy, S.; Chakraborty, A.; Chattopadhyay, B.; Bhattacharya, A.; Mukherjee, A. K.; Ghosh, R. *Tetrahedron* **2010**, *66*, 8512–8521.

17. (a) Mohanakrishnan, A. K.; Prakash, C.; Ramesh, N. *Tetrahedron* **2006**, *62*, 3242–3247; (b) Jana, U.; Maiti, S.; Biswas, S. *Tetrahedron Lett.* **2007**, *48*, 7160–7163; (c) Duan, Z.; Xuan, X.; Wu, Y. *Tetrahedron Lett.* **2007**, *29*, 5157–5159; (d) Bonnamour, J.; Bolm, C. *Org. Lett.* **2008**, *10*, 2665–2667; (e) Biswas, S.; Maiti, S.; Jana, U. *Eur. J. Org. Chem.* **2009**, *14*, 2354–2359; (f) Wang, K.; Lu, M.; Yu, A.; Zhu, X.; Wang, Q. *J. Org. Chem.* **2009**, *74*, 935–938; (g) Zou, T.; Pi, S.-S.; Li, J.-H. *Org. Lett.* **2009**, *11*, 453–456; (h) Kamal, A.; Srikanth, Y. V. V.; Khan, M. N. A.; Shaik, T. B.; Ashraf, M. *Bioorg. Med. Chem. Lett.* **2010**, *20*, 5229–5231; (i) Liu, C.-R.; Yang, F.-L.; Jin, Y.-Z.; Ma, X.-T.; Cheng, D.-J.; Li, N.; Tian, S.-K. *Org. Lett.* **2010**, *12*, 3832–3835; (j) Yang, L.; Lei, C.-H.; Wang, D.-X.; Huang, Z.-T.; Wang, M.-X. *Org. Lett.* **2010**, *12*, 3918–3921; (k) Dasgupta, F.; Singh, P. P.; Srivastava, H. C. *Carbohydr. Res.* **1980**, *80*, 346–349; (l) Wei, G.; Lv, X.; Du, Y. *Carbohydr. Res.* **2008**, *343*, 3096–3099; (m) Singh, P. P.; Gharia, M. M.; Dasgupta, F.; Srivastava, H. C. *Tetrahedron Lett.* **1977**, 439–440.
18. Cumpstey, I.; Chayajarus, K.; Fairbanks, A. J.; Redgrave, A. J.; Seward, C. M. P. *Tetrahedron: Asymmetry* **2004**, *15*, 3207–3221.
19. Alpe, M.; Oscarson, S. *Carbohydr. Res.* **2002**, *337*, 1715–1722.
20. Zeng, Y.; Zhang, W.; Ning, J.; Kong, F. *Carbohydr. Res.* **2002**, *337*, 2383–2391.
21. Selke, R.; Schwarze, M.; Baudisch, H.; Grassert, I.; Michalik, M.; Oehme, G.; Stoll, N.; Costisella, B. *J. Mol. Catal.* **1993**, *84*, 223–237.
22. (a) Padrón, J. I.; Vázquez, J. T. *Tetrahedron: Asymmetry* **1995**, *6*, 857–858; (b) Rodebaugh, R.; Debenham, J. S.; Fraser-Reid, B. *Tetrahedron Lett.* **1996**, *37*, 5477–5478.
23. (a) Wang, Z.; Zhou, L.; El-Boubbou, K.; Ye, X.; Huang, X. *J. Org. Chem.* **2007**, *72*, 6409–6420; (b) Colquhoun, I. J.; Defernez, M.; Morris, V. J. *Carbohydr. Res.* **1995**, *269*, 319–331; (c) Katzenellenbogen, E.; Kocharova, N. A.; Zatonsky, G. V.; Shashkov, A. S.; Korzeniowska-Kowal, A.; Gamian, A.; Bogulska, M.; Knirel, Y. A. *Carbohydr. Res.* **2005**, *340*, 263–270; (d) Arbatsky, N. P.; Wang, M.; Shashkov, A. S.; Feng, L.; Knirel, Y. A.; Wang, L. *Carbohydr. Res.* **2010**, *345*, 2095–2098; (e) Ray, B.; Loutelier-Bourhis, C.; Lange, C.; Condamine, E.; Driouich, A.; Lerouge, P. *Carbohydr. Res.* **2004**, *339*, 201–208.
24. Larsen, K.; Olsen, C. E.; Motawia, M. S. *Carbohydr. Res.* **2003**, *338*, 199–202.
25. Takeo, K.; Fukatsu, T.; Yasato, T. *Carbohydr. Res.* **1982**, *107*, 71–90.
26. Fazli, A.; Bradley, S. J.; Kiefel, M. J.; Jolly, C.; Holmes, I. J.; Itzstein, M. V. *J. Med. Chem.* **2001**, *44*, 3292–3301.