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Synthesis of photolabile group protected anomeric acetals and its application in carbohydrate synthesis with the assistance of continuous flow photo-reactor

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Selective deprotection of photolabile anomeric 2-nitrobenzyl acetals was achieved using continuous flow photo-reactor (UV radiation at 355 nm) in methanol-water. Various protecting groups such as acetyl, benzyl, benzoyl, benzylidine, TBS, etc. were found to be highly stable during the photolysis.

Keywords: Photolabile protecting group, anomeric acetals, methanol, UV-radiation, photo-reactor.

Introduction

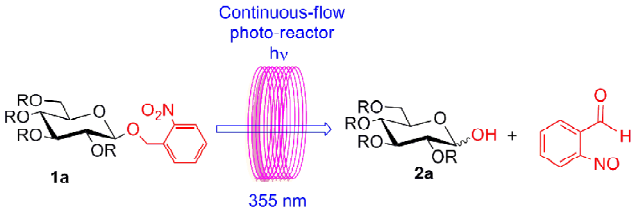
Carbohydrates are biomolecules which take part in many biological functions[1]. Structurally well-defined carbohydrate molecules are essential to understand the different roles of glycans in biological systems[2]. In this context, protecting groups play a very important role in the synthesis of structurally pure oligosaccharides[3]. It is well known that the chemistry of sugar molecules is majorly dominated by the chemistry of the anomeric centre[4]. In this perspective, particular attention is required during the selection of anomeric protecting groups[5]. It is expected that the ideal anomeric protecting group should be stable under different reaction conditions to allow functional group manipulations in the carbohydrate building blocks. Moreover, it should be orthogonal to other protecting groups placed in the building blocks which can be selectively cleaved to yield desired hemiacetals for the preparation of active glycosyl donors or biologically relevant glycoconjugates[5]. Among the different protecting groups, methyl, allyl, pentenyl and *p*-methoxyphenyl groups are most commonly used at the anomeric position[6]. These acetals provide hemiacetals upon the selective deprotection with different chemical reagents. Alternatively, hydrolysis of thioglycosides regenerates the hydroxyl group at the anomeric position. Recently, Nitz group demonstrated the use of N,O-dimethylhydroxylamine as an anomeric protecting group which can be cleaved using NCS/water to obtain hemiacetal[7].

Nevertheless, one of the common problems encountered in carbohydrate synthesis is the removal of a specific protecting group selectively. In other words, conditions used for removal of one protecting group will often also cleave other protecting groups within the building blocks. Therefore, the development of other types of protecting groups, which remain stable under various reaction conditions and can be selectively deprotected under mild conditions, remains an important goal.

Photolabile organic molecules have been widely used in organic synthesis as photo-removable protecting groups and in chemical biology as "caged compounds" to explore diverse biological processes[8]. Removal of photolabile protecting groups (PPGs) can be effected by light ($h\nu$) in the absence of any reagents. This feature is particularly beneficial if access to the reaction site is difficult or if chemical reagents are of limited use. Photolabile protecting groups have been explored in the context of natural product synthesis while their application to oligosaccharide synthesis remains less explored[9]. One of the reasons for limited use of PPGs in carbohydrate synthesis might be low efficiency of the conventional batch techniques that have been used in the past decades to carry out photochemical reactions[10]. However, the recent development in photochemical reactions i.e. use of continuous-flow photo-reactors overcome the challenges faced with the use of batch reactors. The proximity of compounds to the UV lamp in continuous-flow photo-reactor en-

sures effective irradiation which results in good yield of desired products[11]. Hence, we envisioned that photolabile protecting groups might be useful in oligosaccharide synthesis when continuous flow photo-reactors are used. In this context, we have recently explored the synthesis of a photolabile group protected (PPG) uronic acid building blocks and their applications in carbohydrate synthesis with the assistance of continuous flow photo-reactor[12]. In continuation of our previous works in carbohydrate synthesis[13], here we have investigated the deprotection of anomeric photolabile protecting group (PPG) in continuous flow photo-reactor.

Among different photolabile protecting groups, 2-nitrobenzyl group containing compounds are most widely used in many organic syntheses[14] as they are commercially available, cheap and relatively stable under different reaction conditions. Considering this fact, here we have synthesized different monosaccharide building blocks having the 2-nitrobenzyl group at the anomeric position and evaluated their deprotection in a continuous flow photo-reactor (Scheme 1).



Scheme 1. Continuous flow reactor assisted deprotection of photolabile group protected anomeric acetals.

Results and discussion

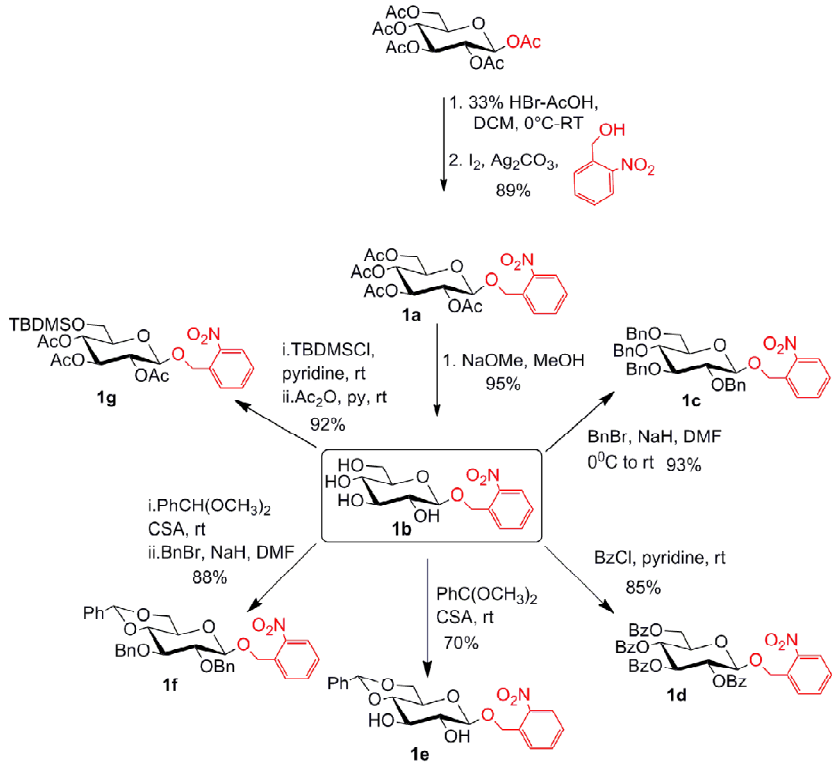
Preparation of anomeric photolabile groups protected monosaccharide building blocks:

Initially, the preparation of 2-nitrobenzyl protected β-D-glucopyranosides, **1a-1g** was accomplished starting from β-D-glucose pentaacetate as shown in Scheme 2. The compound 2-nitrobenzyl-2,3,4,6-tetra-*O*-acetyl-D-glucopyranoside **(1a)** was achieved in excellent yield from β-D-glucose pentaacetate in two steps i.e. bromination followed by silver mediated glycosylation[15]. Further, the treatment of compound **1a** with a catalytic amount of sodium methoxide in methanol provides 2-nitrobenzyl-β-D-glucopyranoside (**1b**) in quantitative yield. The compound **1b** was used as the starting material for the preparation of various anomeric photolabile group protected glucopyranoside building blocks **1c-1g**. For instance, the reaction of compound **1b** with benzyl bromide/NaH and benzoyl chloride/pyridine provided benzylated (**1c**) and benzoylated (**1d**) compounds, respectively, in good yields. On the other hand, the reaction of compound **1b** with benzaldehyde dimethyl acetal in the presence of camphorsulfonic acid (CSA) provided **1e** in 70% yield. Further, the reaction of **1e** with benzyl bromide/NaH gave the compound **1f** in 88% yield. Selective protection of primary alcohol in compound **1b** with *tert*-butyldimethylsilyl (TBS) followed by acetylation provided the compound **1g** in good yield. In addition to glucopyranosides, using similar procedures, we have accomplished the synthesis of anomeric photolabile group protected mannopyranosides **1h-1i** and galactopyranoside **1j** in good yields as shown in Schemes 3 and 4, respectively. It is worth mentioning that during the protecting group manipulation, the anomeric 2-nitrobenzyl group has remained intact.

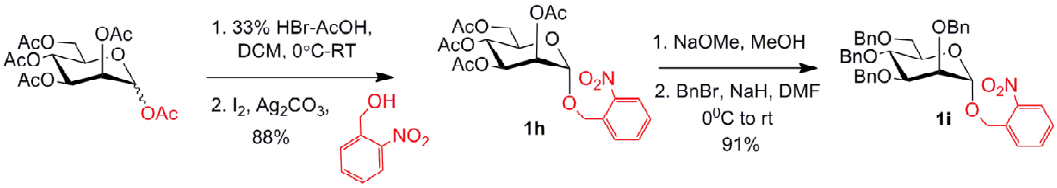
Deprotection of anomeric 2-nitrobenzyl acetals in continuous flow photo-reactor:

To find the best deprotection condition, the compound 2-nitrobenzyl-2,3,4,6-tetra-*O*-acetyl-D-glucopyranoside (**1a**) was subjected to photolysis in the continuous flow photo-reactor (Fig. 1) using different polar solvents including1,4-dioxane, DMF, acetonitrile, DCM, THF and methanol (Table 1, entries 1–6)[12]. Among them, methanol was found to be an efficient medium that provides 51% of the desired hemiacetal **2a** within three minutes (Table 1, entry 6) while other solvents gave relatively low yields. Further, the reaction was investigated in methanol-water mixture (6:1), which provided the desired product in 69% (Table 1, entry 7). Hence, the deprotection was investigated with extended reaction time in a methanol-water mixture solvent (Table 1, entries 8–10). To our delight, the deprotection of anomeric 2-nitrobenzyl acetal was achieved quantitatively (98%) in 15 min (Table 1, entry 9). It is important to note that only 51% of the hemiacetal was obtained under batch reaction conditions even after 4 h (Table 1, entries 11–13). This data clearly indicates the efficiency of continuous flow photo-reactor over batch reactors.

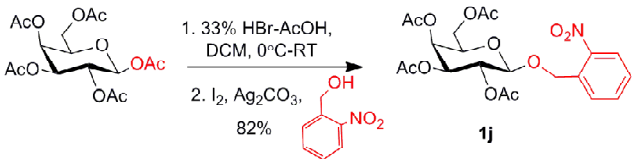
With optimized conditions in hand, deprotection of anomeric PPG protected monosaccharide building blocks **1b-1j** was investigated using the continuous flow photo-reactor (Table 2). Initially, glucopyranoside derivatives **1b-1g** were



Scheme 2. Synthesis of anomeric 2-nitrobenzyl protected β-D-glucopyranosides.



Scheme 3. Synthesis of anomeric 2-nitrobenzyl protected β-D-mannopyranosides.



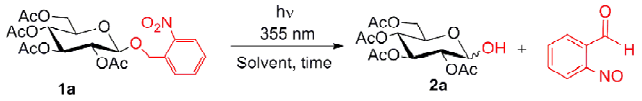
Scheme 4. Synthesis of anomeric 2-nitrobenzyl protected β-D-galactopyranoside.

subjected to photolysis under optimized condition. To our delight, selective removal of the 2-nitrobenzyl group was obtained in quantitative yields while other protecting groups such as acetyl, benzoyl, benzyl, benzylidene and TBS were intact during the photo-cleavage. Interestingly, D-glucose (**2b**) was released from 2-nitrobenzyl-β-D-glucopyranoside (**1b**) in 79% yield under optimized conditions. Similar to glucopyranosides, deprotection of 2-nitrobenzyl group in mannopyranosides **1h-1i** and galactopyranoside **1j** was also accomplished in excellent yield in 15 min.

Applications in carbohydrate synthesis:

Further, we have investigated the applicability of the above procedure in carbohydrate synthesis. In this context, 2.0 g of 2-nitrobenzyl-2,3,4,6-tetra-*O*-benzyl-D-glucopyranoside (**1c**) was subjected to the anomeric deprotection using continuous flow photo-reactor at 355 nm for 30 min (10 cycles). To our delight, the hemiacetal **2c** was obtained in quantitative yield (96%) from which glycosylimidate donor **1aa** was pre-

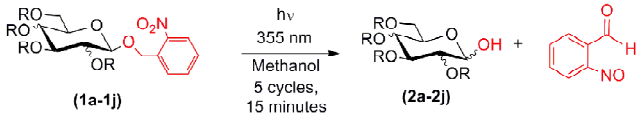
Table 1. Optimization of photo-deprotection using flow and batch reactor[a,b]

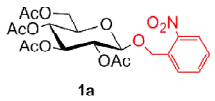
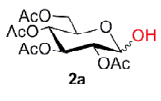
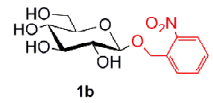
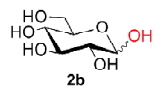
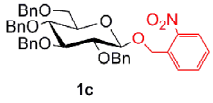
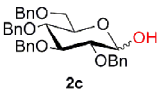
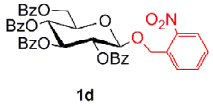
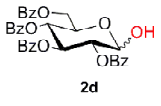
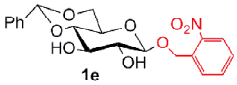
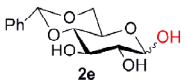
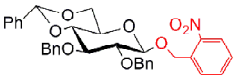
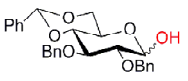
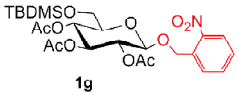
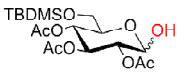
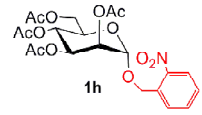
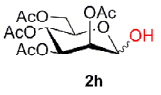
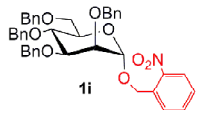
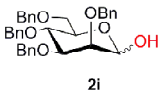
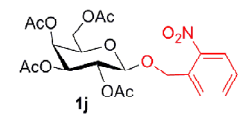
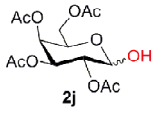


Entry	Solvent	No. of cycle	Time (min)	Yield (%)
1	1,4-Dioxane	1	3	12
2	DMF	1	3	09
3	CH_3CN	1	3	43
4	CH_2Cl_2	1	3	< 5
5	THF	1	3	30
6	CH_3OH	1	3	51
7	CH_3OH-H_2O (6:1)	1	3	69
8	CH_3OH-H_2O (6:1)	3	9	85
9	CH_3OH-H_2O (6:1)	5	15	98
10	CH_3OH-H_2O (6:1)	9	27	98
11	CH_3OH-H_2O (6:1)	Batch reactor	60	23
12	CH_3OH-H_2O (6:1)	Batch reactor	120	40
13	CH_3OH-H_2O (6:1)	Batch reactor	240	51

[a]The reactions were carried out using 250 mg of compound. 0.005 *M* solution of **1a** was prepared in different solvents and subjected to photolysis in the continuous flow photo-reactor. [b]Isolated yield.

Table 2. Photo-deprotection of various PPG protected anomeric acetal building blocks[a,b]



Entry	Substrate	Product	Yield (%)
1	 1a	 2a	98
2	 1b	 2b	79
3	 1c	 2c	99
4	 1d	 2d	96
5	 1e	 2e	94
6	 1f	 2f	97
7	 1g	 2g	95
8	 1h	 2h	95
9	 1i	 2i	97
10	 1j	 2j	90

[a]0.005 *M* solution of the 2-nitrobenzyl acetal was subjected for photolysis with the flow rate 50 RPM. [b]Isolated yield.

pared using trichloroacetonitrile and DBU at 0°C in DCM. Further, the compound **1aa** was then subjected to the glycosylation with benzyl alcohol (**3a**) and 1,2,3,4-di-*O*-isopropylidene-β-D-galactopyranoside (**3b**) acceptors in presence of tris(pentafluorophenyl)borane catalyst to obtain the glycosylated products **4a** and **4b** in good yields (Scheme 5).

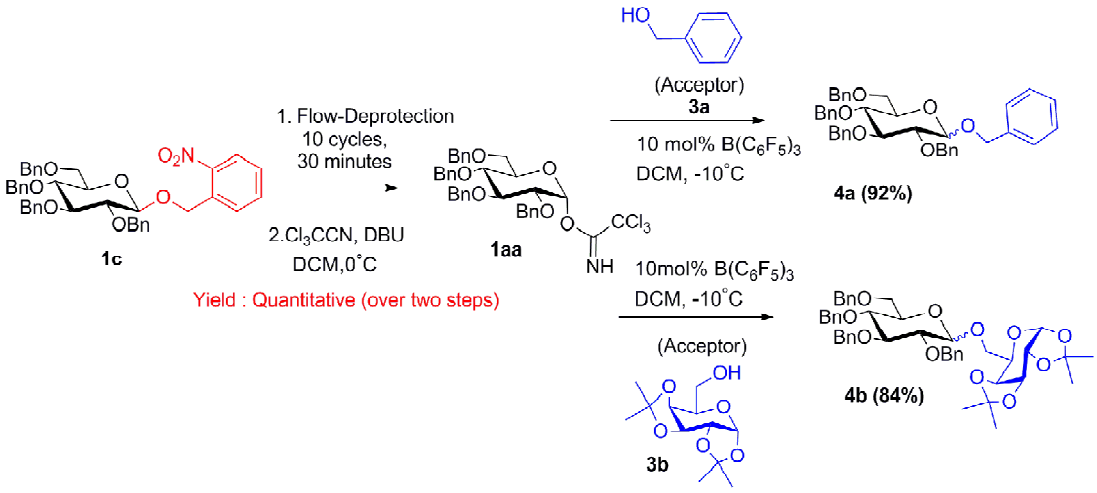
Conclusions

The use of photolabile protecting group at anomeric position in oligosaccharide synthesis was investigated. The photolabile protecting group can be selectively cleaved in excellent yield in the presence of other protecting groups under continuous flow photo-reactor in a short span of time. This protocol does not require acidic or basic condition as well as any chemical reagent; hence it may be helpful for complex oligosaccharides synthesis.

Experimental

*Procedure for synthesis of 2-nitrobenzyl-2,3,4,6-tetra-O-acetyl-β-D-glucopyranoside (**1a**)[15]:*

To a solution of glucose pentaacetate (5 g, 12.8 mmol) in DCM (15 mL), HBr (33% in AcOH, 17.5 mL, 102.5 mmol) was added dropwise at 0°C. The resulting mixture was stirred at room temperature under nitrogen for 12 h. The resulting solution was quenched with aq. $NaHCO_3$, extracted with



Scheme 5. Anomeric photo-deprotection followed by glycosylation reactions via glycosylimidate donor (**1aa**).

DCM (300 mL) and dried over anhydrous sodium sulphate. The organic layer was evaporated to obtain glycosylbromide in quantitative yield (>5.1 g, 97%).

Silver carbonate (10.0 g, 36.4 mmol) and pinch of iodine were added to a solution of 2-nitrobenzyl alcohol (9.31 g, 60.8 mmol) in dry CH_2Cl_2. A solution of glycosylbromide (5.0 g, 12.16 mmol) in dry DCM was then added dropwise and allowed to stir for 16 h at room temperature. The reaction mixture was diluted with DCM and filtered through Celite. The resulting solution was concentrated *in vacuo* and purified by column chromatography to obtain the product **1a** as white solid (5.23 g, 89%), m.p. 67–68°C; R_f = 0.5 (50% EtOAc/hexane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.07 (d, *J* 8.2 Hz, 1H), 7.67 (dd, *J* 25.2, 7.6 Hz, 2H), 7.45 (s, 1H), 5.29–5.20 (m, 2H), 5.16–5.09 (m, 2H), 5.04 (d, *J* 14.7 Hz, 1H), 4.67 (d, *J* 7.9 Hz, 1H), 4.29 (dd, *J* 12.3, 4.8 Hz, 1H), 4.18–4.11 (m, 1H), 3.75 (ddd, *J* 9.9, 4.7, 2.2 Hz, 1H), 2.08 (s, 3H), 2.05 (s, 3H), 2.02 (s, 3H), 2.01 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 170.6, 170.2, 169.4, 169.4, 147.0, 133.8, 133.4, 128.8, 128.4, 124.7, 100.5, 72.7, 71.9, 71.2, 68.3, 68.2, 61.8, 20.7, 20.6, 20.6, 20.5; HRMS: Calcd. for $C_{21}H_{25}NO_{12}$ $[M+H]^+$: 483.1377, Obser. 483.1379.

*2-Nitrobenzyl-β-D-glucopyranoside (**1b**)*[15]*:*

Sodium methoxide (500 mg) was added to a stirred solution of **1a** (5.0 g, 10.34 mmol) in dry MeOH (50 mL) and allowed to stir for 30 min at room temperature. The resulting solution was then neutralized with Amberlite-H^+ and filtered. The filtrate was concentrated *in vacuo* and subjected to column chromatography (5% methanol in EtOAc) to obtain **1b** as white solid (3.10 g, 95%). m.p. 125°C; R_f = 0.15 (5% methanol/EtOAc); ^{1}H NMR (500 MHz, CD_3OD): δ 8.03 (d, *J* 8.1 Hz, 1H), 7.99 (d, *J* 7.7 Hz, 1H), 7.68 (t, *J* 7.2 Hz, 1H), 7.47 (t, *J* 7.7 Hz, 1H), 5.15 (d, *J* 15.3 Hz, 2H), 4.41 (d, *J* 7.6 Hz, 1H), 3.85 (d, *J* 11.1 Hz, 1H), 3.66 (dd, *J* 4.9, 11.9 Hz, 1H), 3.29–3.40 (m, 4H); ^{13}C NMR (125 MHz, CD_3OD): δ 148.7, 135.7, 134.7, 130.3, 129.2, 125.5, 104.0, 78.0, 75.1, 71.5, 68.4, 62.6; HRMS: Calcd. for $C_{13}H_{17}NO_8$ $[M+H]^+$: 315.0954, Obser. 315.0958.

*2-Nitrobenzyl-2,3,4,6-tetra-O-benzyl-β-D-glucopyranoside (**1c**):*

To a solution of **1b** (500 mg, 1.59 mmol) in DMF (15 mL) was added NaH (305 mg, 12.69 mmol) portion wise at 0°C and stirred for 20 min at the same temperature. Then the reaction mixture was brought to room temperature and benzyl bromide (0.94 mL, 7.93 mmol) was added. After completion, the reaction mixture was diluted with ethyl acetate (200 mL) and washed using ice cold water and brine. The organic layer was separated, dried over anhydrous Na_2SO_4, filtered. The filtrate was concentrated *in vacuo* and purified using column chromatography to obtain yellowish syrup (997 mg, 93% yield); R_f = 0.5 (20% EtOAc/hexane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.45–7.32 (m, 22H), 7.23–7.20 (m, 2H), 5.07–4.98 (m, 2H), 4.91–4.84 (m, 2H), 4.80–4.71 (m, 3H), 4.62 (dt, *J* 16.5, 7.5 Hz, 3H), 4.53 (d, *J* 11.2 Hz, 1H), 3.85 (dd, *J* 20.4, 10.2 Hz, 1H), 3.78–3.64 (m, 3H), 3.61–3.54 (m, 2H); ^{13}C

NMR (125 MHz, $CDCl_3$): δ 138.6, 138.4, 138.2, 138.1, 137.5, 128.4, 128.4, 128.2, 128.0, 128.0, 127.9, 127.9, 127.8, 127.8, 127.6, 127.6, 102.6, 84.7, 82.3, 77.9, 75.7, 75.0, 74.9, 73.5, 71.2, 68.9; HRMS: Calcd. for $C_{41}H_{41}NO_8$ $[M+H]^+$: 675.2832, Obser. 675.2830.

*2-Nitrobenzyl-2,3,4,6-tetra-O-benzoyl-β-D-glucopyranoside (**1d**):*

To a solution of **1b** (500 mg, 1.59 mmol) in pyridine (10 mL) was added benzoyl chloride (0.92 mL, 7.93 mmol) and stirred for overnight. Ethyl acetate (200 mL) was added to the solution and washed using 0.1 *N* HCl solution and brine. The organic layer was separated, dried over anhydrous Na_2SO_4, filtered. The filtrate was concentrated *in vacuo* and purified using column chromatography to obtain yellowish syrup (986 mg, 85% yield); R_f = 0.5 (30% EtOAc/hexane); ^1H NMR (500 MHz, $CDCl_3$): δ 8.01–7.37 (m, 24H), 5.64–5.56 (m, 1H), 5.36 (d, *J* 15.4 Hz, 1H), 5.13 (d, *J* 15.6 Hz, 1H), 4.93 (t, *J* 6.3 Hz, 1H), 4.80 (dd, *J* 11.9, 4.1 Hz, 1H), 4.71–4.67 (m, 1H), 4.46 (dd, *J* 11.7, 5.6 Hz, 1H), 3.98–3.94 (m, 1H), 3.89 (d, *J* 7.3 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 167.1, 167.1, 166.7, 165.3, 146.6, 134.0, 133.8, 133.5, 133.4, 129.9, 129.9, 129.9, 129.8, 129.7, 129.7, 128.5, 128.4, 128.4, 124.6, 100.8, 76.1, 74.7, 72.2, 71.5, 69.5, 67.9, 63.3; HRMS: Calcd. for $C_{41}H_{33}NO_{12}$ $[M+H]^+$: 731.2003, Obser. 731.2006.

*2-Nitrobenzyl-4,6-O-benzylidene-β-D-glucopyranoside (**1e**)[16]:*

Camphorsulphonic acid (147 mg, 0.63 mmol) was added to a solution of **1a** (500 mg, 1.59 mmol) in acetonitrile (10 mL) and stirred for 10 min to which benzaldehydedimethylacetal (0.48 mL, 3.17 mmol). The resulting mixture was stirred for overnight and concentrated on rotary vapour. The resulting crude was dissolved in ethyl acetate and washed with saturated $NaHCO_3$ and brine solution. The organic layer was dried over anhydrous Na_2SO_4 and concentrated *in vacuo*. The crude material was purified using column chromatography to obtain pale yellow solid **(**448 mg, 70% yield); m.p. 165°C; R_f = 0.5 (20% EtOAc/hexane); ^1H NMR (300 MHz, $CDCl_3$): δ 8.07 (d, *J* 8.1 Hz, 1H), 7.84 (d, *J* 7.8 Hz, 1H), 7.65 (t, *J* 7.6 Hz, 1H), 7.50–7.35 (m, 6H), 5.52 (s, 1H), 5.10 and 5.26 (AB, *J* 14.7 Hz, 2H), 4.55 (d, *J* 7.5 Hz, 1H), 4.35 (dd, *J* 4.8, 10.5 Hz, 1H), 3.85–3.72 (m, 2H), 3.62–3.43 (m, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 147.3, 136.9, 133.7, 133.6, 129.3, 129.1, 128.3, 128.3, 126.3, 124.7, 102.8, 101.9, 80.4, 74.6, 73.3, 68.5, 68.1, 66.4. HRMS: Calcd. for $C_{20}H_{21}NO_8$ $[M+H]^+$: 403.1267, Obser. 403.1270.

*2-Nitrobenzyl-2,3-di-O-benzyl-4,6-O-benzylidene-β-D-glucopyranoside (**1f**)[16]:*

To a solution of **1e** (410 mg, 1 mmol) in DMF (10 mL) at 0°C was added sodium hydride (98 mg, 4 mmol) and stirred for 20 min after which benzyl bromide (0.29 mL, 2.44 mmol) was added. After completion, the reaction mixture was diluted with ethyl acetate (200 mL) and washed using ice cold water and brine. The organic layer was separated, dried over anhydrous Na_2SO_4, filtered. The filtrate was concentrated *in vacuo* and purified using column chromatography to obtain white solid (522 mg, 88% yield); m.p. 139–140°C; R_f = 0.5 (20% EtOAc/hexane); ^1H NMR (500 MHz, $CDCl_3$): δ 8.15 (dd, *J* 8.1, 1.3 Hz, 1H), 7.92 (d, *J* 7.7 Hz, 1H), 7.33–7.60 (m, 17H), 5.65 (s, 1H), 5.38 (d, *J* 15.6 Hz, 1H), 5.19 (d, *J* 15.6 Hz, 1H), 5.03 (d, *J* 11.4 Hz, 1H), 4.97 (s, 1H), 4.96 (s, 1H), 4.89 (d, *J* 11.4 Hz, 1H), 4.74 (d, *J* 7.8 Hz, 1H), 4.45 (dd, *J* 5.0, 10.4 Hz, 1H), 3.78–3.92 (m, 3H), 3.69 (t, *J* 7.8, 8.2 Hz, 1H), 3.47–3.55 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 146.7, 138.3, 138.0, 137.1, 134.1, 128.8, 128.4, 128.2, 128.2, 128.1, 128.1, 128.1, 127.9, 127.9,127.6, 127.5, 125.8, 124.6, 103.0, 101.0, 81.9, 81.4, 80.9, 75.4, 75.0, 68.5, 67.7, 65.9; HRMS: Calcd. for $C_{34}H_{33}NO_8$ $[M+H]^+$: 583.2206, Obser. 583.2202.

*2-Nitrobenzyl-2,3,4-tri-O-acetyl-6-O-(tert-butyldimethylsilyl)-β-D-glucopyranoside (**1g**):*

To a solution of **1b** (500 mg, 1.59 mmol) in pyridine (10 mL) was added *tert*-butyldimethylsilyl chloride (287 mg, 1.9 mmol) and stirred overnight. The reaction mixture was dissolved with ethyl acetate (200 mL) and washed using 0.1 *N* HCl solution and brine. The organic layer was separated, dried over anhydrous Na_2SO_4, filtered and concentrated *in vacuo*. The crude material was then dissolved in pyridine (10 mL) to which acetic anhydride (0.96 mL, 10.11 mmol) and 4-DMAP (10 mol%) were added. The resulting mixture was stirred for overnight and evaporated to dryness using rotaevaporator. The crude material was purified using column chromatography to obtain pale yellow oil (861 mg, 92% yield); R_f = 0.5 (20% EtOAc/hexane); ^1H NMR (500 MHz, $CDCl_3$): δ 7.29 (d, *J* 3.7 Hz, 4H), 5.60–5.42 (m, 1H), 5.09 (d, *J* 13.5 Hz, 1H), 4.89 (d, *J* 10.4 Hz, 1H), 4.38–2.86 (m, 6H), 2.10 (s, 3H), 2.03 (d, *J* 3.0 Hz, 3H), 1.27 (s, 3H), 0.91 (s, 9H), 0.07 (s, 6H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 170.3, 170.1, 169.5, 128.3, 127.9, 127.0, 95.5, 90.0, 75.9, 74.9, 73.5, 72.6,

71.2, 70.2, 69.8, 68.9, 68.9, 62.2, 25.9, 25.8, 20.7, 20.7, 20.6, 18.4; HRMS: Calcd. for $C_{25}H_{37}NO_{11}Si$ $[M+H]^+$: 555.2136, Obser. 555.2133.

*2-Nitrobenzyl-2,3,4,6-tetra-O-acetyl-α-D-mannopyranoside (**1h**):*

Using a similar procedure described in the synthesis of **1a**, 2-nitrobenzyl-2,3,4,6-tetra-*O*-acetyl-α-D-mannopyranoside **(1h)** was prepared from mannosylpentaacetate (2.0 g, 5.1 mmol). The desired product **1h** was obtained as yellowish syrup (2.18 g, 88% yield); R_f = 0.4 (50% EtOAc/hexane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.11 (d, *J* 8.1 Hz, 1H), 7.77 (d, *J* 7.7 Hz, 1H), 7.70 (t, *J* 7.4 Hz, 1H), 7.49 (t, *J* 7.6 Hz, 1H), 5.41–5.37 (m, 2H), 5.30 (t, *J* 9.9 Hz, 1H), 5.16 (d, *J* 15.0 Hz, 1H), 4.99–4.90 (m, 2H), 4.28 (dd, *J* 12.2, 5.8 Hz, 1H), 4.10 (d, *J* 12.1 Hz, 1H), 4.02 (dd, *J* 9.3, 6.2 Hz, 1H), 2.16 (s, 3H), 2.10 (s, 3H), 2.03 (s, 3H), 2.01 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 170.7, 170.0, 170.0, 169.7, 147.1, 134.0, 133.0, 128.5, 128.5, 124.9, 97.4, 69.3, 69.1, 69.0, 66.2, 66.0, 62.3, 20.8, 20.6; HRMS: Calcd. for $C_{21}H_{25}NO_{12}$ $[M+H]^+$: 483.1377, Obser. 483.1374.

*2-Nitrobenzyl-2,3,4,6-tetra-O-benzyl-β-D-mannopyranoside (**1i**):*

Sodium methoxide (100 mg) was added to a stirred solution of **1h** (1.0 g, 2.07 mmol) in dry MeOH (25 mL) and stirred for 30 min. The resulting solution was then neutralized with Amberlite-H^+, filtered, and concentrated *in vacuo*. The crude material was then dissolved in DMF (15 mL) and NaH was added (347 mg, 14.5 mmol) portion wise at 0°C and stirred for 20 min. Then the reaction mixture was brought to room temperature and benzyl bromide (1.34 mL, 10.34 mmol) was added. After completion, the reaction mixture was diluted with ethyl acetate (200 ml) and washed using ice cold water and brine. The organic layer was separated, dried over anhydrous Na_2SO_4 and filtered. The filtrate was concentrated *in vacuo* and purified using column chromatography to obtain **1i** as yellowish syrup (1.27 g, 91% yield); R_f = 0.5 (20% EtOAc/hexane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.39–7.18 (m, 24H), 5.41–5.07 (m, 2H), 4.93 (d, *J* 11.7 Hz, 1H), 4.81 (d, *J* 12.0 Hz, 1H), 4.75–4.69 (m, 1H), 4.64 (s, 1H), 4.59–4.55 (m, 2H), 4.49 (d, *J* 10.4 Hz, 1H), 4.47–4.18 (m, 3H), 4.15–3.96 (m, 1H), 3.84–3.66 (m, 2H), 3.64–3.61 (m, 1H), 3.51–3.39 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 145.5, 142.2, 137.6, 135.5, 132.4, 130.8, 130.4, 130.3, 130.2, 130.1, 129.8, 129.4, 129.0, 128.8, 128.4, 128.4, 128.3, 128.3, 128.2, 128.2, 128.1, 127.9, 127.9, 127.8, 127.7, 127.6, 127.6, 127.4, 127.4, 126.7, 125.8, 125.7, 123.8, 122.6, 113.0, 95.4, 79.5, 77.7, 73.3, 72.5, 72.2, 70.4, 69.9, 68.9; HRMS: Calcd. for $C_{41}H_{41}NO_8$ $[M+H]^+$: 675.2832, Obser. 675.2828.

*2-Nitrobenzyl-2,3,4,6-tetra-O-acetyl-β-D-galactopyranoside (**1j**)[17]:*

Using a similar procedure described in the synthesis of **1a**, 2-nitrobenzyl-2,3,4,6-tetra-*O*-acetyl-β-D-galactopyranoside **1j** was prepared from galactosylpentaacetate (2.0 g, 5.1 mmol). The compound **1j** was obtained as yellowish syrup (2.03 g, 82% yield); R_f = 0.4 (50% EtOAc/hexane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.09 (d, *J* 7.9 Hz, 1H), 7.73 (d, *J* 7.9 Hz, 1H), 7.65 (t, *J* 7.9 Hz, 1H), 7.47 (t, *J* 7.9 Hz, 1H), 5.43 (d, *J* 3.4 Hz, 1H), 5.34 (dd, *J* 8.1, 10.4 Hz, 1H), 5.28 (d, *J* 14.8 Hz, 1H), 5.08–5.07 (m, 1H), 5.06 (d, *J* 14.8 Hz, 1H), 4.66 (d, *J* 8.1 Hz, 1H), 4.21 (dd, *J* 6.7, 11.4 Hz, 1H), 4.15 (dd, *J* 6.7, 11.4 Hz, 1H), 3.40–3.89 (m, 1H), 2.17 (s, 3H), 2.07 (s, 3H), 2.06 (s, 3H), 2.00 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 170.4, 170.2, 170.1, 169.6, 147.0, 133.5, 133.9, 128.8, 128.4, 124.8, 101.0, 70.9, 70.8, 68.8, 68.2, 67.0, 61.2, 20.9, 20.8, 20.7, 20.6; HRMS: Calcd. for $C_{21}H_{25}NO_{12}$ $[M+H]^+$: 483.1377, Obser. 483.1380.

Experimental procedure for photo-deprotection of 2-nitrobenzyl acetals:

The deprotection of anomeric 2-nitrobenzyl acetals was carried out using continuous flow photo-reactor[12]. All reactions were carried out with 250 mg of compounds. Approximately, 0.005 *M* solution of photolabile protected glycosyl-acetals were prepared in methanol-H_2O (6:1) and circulated in the flow reactor with the help of peristaltic pump. The flow rate was controlled using peristaltic pump (50 RPM) which required approx. 3 min for completing one cycle. Total five cycles were repeated after which the solvent was evaporated and purified using column chromatography.

Analytical data of anomeric deprotected monosaccharides:

*2,3,4,6-Tetra-O-acetyl-D-glucopyranoside (**2a**)[18]:* Colourless viscous liquid (85 mg, 98% yield); R_f = 0.4 (60% EtOAc/hexane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 5.50 (t, *J* 9.8 Hz, 1H), 5.42 (d, *J* 3.5 Hz, 1H), 5.05 (t, *J* 9.7 Hz, 1H), 4.85 (dd, *J* 10.3, 3.6 Hz, 1H), 4.25–4.18 (m, 2H), 4.13–4.08 (m, 1H), 2.06 (d, *J* 5.7 Hz, 6H), 1.99 (d, *J* 8.5 Hz, 6H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 171.1, 170.4, 169.8, 169.7, 95.4, 90.1,

71.2, 69.9, 68.5, 67.1, 62.0, 20.8, 20.7, 20.7, 20.7; HRMS: Calcd. for $C_{14}H_{20}O_{10}$ $[M+H]^+$: 348.1056, Obser. 348.1059.

*D-Glucopyranoside (**2b**)[19]:* White solid (36 mg, 79% yield); R_f = 0.1 (10 % MeOH/$CHCl_3$); ^{1}H NMR (500 MHz, D_2O): δ 5.25 (d, *J* 5.93 Hz, 1H), 4.67 (d, *J* 7.90 Hz, 1H), 3.94–3.84 (m, 2H), 3.81–3.72 (m, 3H), 3.63–3.40 (m, 6H), 3.27–3.25 (m, 1H); ^{13}C NMR (125 MHz, D_2O): δ 98.6, 94.8, 78.6, 78.5, 76.9, 75.5, 74.2, 74.1, 72.4, 63.5, 63.4.

*2,3,4,6-Tetra-O-benzyl-D-glucopyranoside (**2c**)[20]:* Syrupy liquid (134 mg, 99% yield); R_f = 0.4 (20% EtOAc/hexane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.55–7.12 (m, 20H), 5.30 (d, *J* 3.4 Hz, 1H), 5.03 (t, *J* 8.7 Hz, 1H), 4.93–4.75 (m, 4H), 4.65–4.53 (m, 3H), 4.15–4.07 (m, 1H), 3.77–3.58 (m, 5H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 138.7, 138.2, 137.9, 137.8, 128.5, 128.4, 128.3, 128.1, 128.0, 128.0, 127.9, 127.9, 127.9, 91.2, 81.8, 80.0, 77.8, 77.4, 75.7, 75.0, 73.4, 73.1, 70.1, 68.7; HRMS: Calcd. for $C_{34}H_{36}O_6$ $[M+H]^+$: 540.2512, Obser. 540.2515.

*2,3,4,6-Tetra-O-benzoyl-D-glucopyranoside (**2d**)[21]:* Syrupy liquid (143 mg, 96% yield); R_f = 0.4 (30% EtOAc/hexane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.15–8.13 (m, 2H), 8.05–8.03 (m, 2H), 8.00–7.98 (m, 2H), 7.88–7.87 (m, 2H), 7.59–7.55 (m, 2H), 7.51–7.48 (m, 1H), 7.44–7.34 (m, 8H), 7.28 (d, *J* 8.0 Hz, 1H), 6.22 (t, *J* 10.1 Hz, 1H), 6.06 (dd, *J* 10.2, 3.2 Hz, 1H), 5.79 (dd, *J* 3.1, 1.9 Hz, 1H), 5.57 (d, *J* 1.7 Hz, 1H), 4.80 (dd, *J* 12.2, 2.6 Hz, 1H), 4.72 (dd, *J* 10.0, 3.0 Hz, 1H), 4.46 (dd, *J* 12.3, 3.4 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 166.6, 165.8, 165.6, 165.6, 133.5, 133.2, 133.2, 129.9, 129.8, 129.8, 129.3, 129.1, 129.1, 128.6, 128.5, 128.5, 128.5, 128.4, 92.4, 71.1, 70.1, 68.8, 67.0, 62.8; HRMS: Calcd. for $C_{34}H_{28}O_{10}$ $[M+H]^+$: 596.1682, Obser. 596.1685.

*4,6-O-Benzylidene-D-glucopyranoside (**2e**)[22]:* Colourles soil (63 mg, 94% yield); R_f = 0.4 (80% EtOAc/hexane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.50–7.48 (m, 2H), 7.39–7.30 (m, 3H), 5.56 (s, 1H), 5.13 (d, *J* 3.8 Hz, 1H), 4.60 (d, *J* 7.7 Hz, 1H), 4.19 (dd, *J* 4, 10 Hz, 1H), 3.92 (dd, *J* 3.5, 13 Hz, 1H), 3.86 (t, *J* 9.1 Hz, 1H), 3.62 (t, *J* 9.1 Hz, 1H), 3.50–3.39 (m, 1H), 3.23 (dd, *J* 7.7, 8.7 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 139.1, 129.9, 129.1, 129.1, 127.6, 127.6, 103.1, 102.0, 99.0, 94.8, 83.2, 82.5, 77.3, 74.8, 74.5, 71.9, 70.3, 69.8, 67.8, 63.6; HRMS: Calcd. for $C_{13}H_{16}O_6$ $[M+H]^+$: 268.0947, Obser. 268.0944.

*2,3-Di-O-benzyl-4,6-O-benzylidene-D-glucopyranoside (**2f**)[23]:* Colourless oil (109 mg, 97% yield); R_f = 0.4 (30% EtOAc/hexane); α:β, 1:2; ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.50–7.27 (m, 15H), 5.59 (s, 1H), 4.89 (d, *J* 11.1 Hz, 1H), 4.82 (d, *J* 11.1 Hz, 1H), 4.81 (d, *J* 11.0 Hz, 1H), 4.80 (d,*J* 11.0 Hz, 1H), 4.82–4.79 (m, 1H), 4.32 (dd, *J* 10.4, 4.9 Hz, 1H), 3.77 (m, 1H), 3.76–3.72 (m, 1H), 3.70 (t, *J* 9.2 Hz, 1H), 3.46 (ddd, *J* 10.0 , 9.2, 5.0 Hz, 1H), 3.38 (dd, *J* 8.5, 7.7 Hz, 1H), 3.34 (d, *J* 5.8 Hz, 1H); ^{13}C NMR (125 MHz,$CDCl_3$): δ 138.4, 138.2, 137.3, 129.0, 128.9, 128.5, 128.4, 128.3, 128.3, 128.3, 128.2, 128.1, 128.1, 128.1, 128.0, 128.0, 128.0, 127.9, 127.7, 127.7, 126.0, 126.0, 101.3, 101.2, 97.8, 92.2, 83.0, 81.9, 81.6, 80.9, 79.3, 78.3, 75.3, 75.2, 75.1, 73.9, 69.0, 68.7, 66.3, 62.5; HRMS: Calcd. for $C_{27}H_{28}O_6$ $[M+H]^+$: 448.1886, Obser. 448.1889.

*2,3,4-Tri-O-acetyl-6-O-(tert-butyldimethylsilyl)-D-glucopyranoside (**2g**)[24]:* Yellow oil (100 mg, 95% yield); R_f = 0.5 (30% EtOAc/hexane); anomeric mixture (α:β, 2:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 5.52 (dd, *J* 9.8, 9.8 Hz, 1H), 5.44 (dd, *J* 3.5, 3.5 Hz, 1H), 5.24 (dd, *J* 9.3, 9.3 Hz, 1H), 5.09 (dd, *J* 9.5, 9.3 Hz, 1H), 5.06 (dd, *J* 9.9, 9.6 Hz, 1H), 4.80–4.91 (m, 2H), 4.70 (dd, *J* 8.5, 8.1 Hz, 1H), 4.05–4.18 (m, 2H), 3.54–3.77 (m, 4H), 3.42 (d, *J* 8.7 Hz, 1H), 2.99 (d, *J* 3.5 Hz, 1H), 2.08 (s, 6H), 2.04 (s, 3H), 2.01 (s, 9H), 0.88 (s, 18H), 0.04 (s, 12H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 170.7, 170.4, 170.2, 169.9, 169.6, 95.3, 90.0, 74.6, 73.3, 72.7, 71.2, 70.3, 69.7, 69.0, 68.9, 62.3, 25.9, 20.7, 18.4; HRMS: Calcd. for $C_{18}H_{32}O_9Si$ $[M+H]^+$: 420.1816, Obser. 420.1819.

*2,3,4,6-Tetra-O-acetyl-D-mannopyranoside (**2h**)[18]:* Colourless viscous liquid (82 mg, 95% yield); R_f = 0.4 (60% EtOAc/hexane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 5.41 (dd, *J* 10.1, 3.3 Hz, 1H), 5.26 (ddd, *J* 17.7, 16.9, 11.8 Hz, 2H), 4.40 (d, *J* 5.7 Hz, 1H), 4.26–4.21 (m, 2H), 4.12–4.09 (m, 1H), 2.15 (s, 3H), 2.09 (s, 3H), 2.03 (s, 3H), 1.98 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 171.0, 170.3, 170.2, 169.9, 92.2, 70.2, 68.9, 68.4, 66.3, 62.7, 43.9, 21.0, 20.8, 20.8, 20.8; HRMS: Calcd. for $C_{14}H_{20}O_{10}$ $[M+H]^+$: 348.1056, Obser. 348.1053.

*2,3,4,6-Tetra-O-benzyl-D-mannopyranoside (**2i**)[20]:* Colourless oil (131 mg, 97% yield); R_f = 0.4 (20% EtOAc/hexane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.51–7.23 (m, 20H), 5.33 (d, *J* 1.5 Hz, 1H), 4.99 (d, *J* 11.0 Hz, 1H), 4.80 (d, *J* 3.5 Hz, 2H), 4.69 (s, 2H), 4.67–4.56 (m, 3H), 4.50–4.25 (m, 1H), 4.20–4.13 (m, 1H), 4.06 (dd, *J* 9.4, 3.0 Hz, 1H), 3.95 (t, *J* 9.6 Hz, 1H), 3.86 (dd, *J* 2.9, 2.0 Hz, 1H), 3.84–3.71 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 138.6, 138.5, 138.5, 138.0, 128.4, 128.4, 128.1, 128.1, 128.0, 127.9, 127.7, 127.7, 127.7, 127.6,

92.6, 79.9, 75.3, 75.1, 75.1, 73.3, 72.7, 72.2, 71.3, 69.7; HRMS: Calcd. for $C_{34}H_{36}O_6$ $[M+H]^+$: 540.2512, Obser. 540.2510.

*2,3,4,6-Tetra-O-acetyl-D-galactopyranoside (**2j**)*[18]*:* Colourless viscous liquid (78 mg, 90% yield); R_f = 0.4 (60% EtOAc/hexane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 5.54 (t, *J* 3.4 Hz, 1H), 5.49 (d, *J* 2.4 Hz, 1H), 5.42 (dd, *J* 10.8, 3.3 Hz, 1H), 5.18 (dd, *J* 10.8, 3.5 Hz, 1H), 5.08–5.01 (m, 1H), 4.48 (t, *J* 6.5 Hz, 1H), 4.18–4.05 (m, 2H), 2.18–1.99 (m, 12H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 170.8, 170.7, 170.4, 170.4, 170.1, 170.0, 95.6, 90.4, 70.8, 70.7, 70.5, 68.3, 68.1, 67.3, 67.1, 65.9, 61.7, 61.3, 20.7, 20.6, 20.56, 20.52, 20.49, 20.5; HRMS: Calcd. for $C_{14}H_{20}O_{10}$ $[M+H]^+$: 348.1056, Obser. 348.1057.

*Procedure for synthesis of 2,3,4,6-tetra-O-benzyl-D-glucopyranosyl trichloroacetimidate (**1aa**):* To a solution of 2,3,4,6-tetra-*O*-benzyl-D-glucopyranose (**2c**) (0.4 g, 0.74 mmol) in dry CH_2Cl_2 was cooled to 0°C. To this solution trichloroacetonitrile (0.74 mL, 7.40 mmol), and DBU (11 μL, 0.07 mmol) were added and stirred for 2 h at the same temperature. The reaction mixture was evaporated under reduced pressure and residue was purified by column chromatography (SiO_2, hexane:ethyl acetate 90:10) using 1% of Et_3N to provide 2,3,4,6-tetra-*O*-benzyl-D-glucopyranosyl trichloroacetimidate (**1aa**) as a pale yellow viscous oil (0.5 g, 98% yield, α:β, 11:1). R_f = 0.4 (15% EtOAc/hexane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.65 (s, 1H,), 7.39–7.24 (m, 18H), 7.24–7.18 (m, 2H), 6.51 (d, *J* 4 Hz, 1H), 4.95 (d, *J* 11 Hz, 1H), 4.86 (d, *J* 11 Hz, 1H), 4.83 (d, *J* 11 Hz, 1H), 4.75 (d, *J* 12 Hz, 1H), 4.69 (d, *J* 12 Hz, 1H), 4.58 (d, *J* 11 Hz, 1H), 4.55 (d, *J* 12 Hz, 1H), 4.48 (d, *J* 12 Hz, 1H), 4.03 (t, *J* 9 Hz, 1H), 3.99–3.97 (m, 1H), 3.81–3.71 (m, 3H), 3.66 (dd, *J* 11, 2 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 161.2, 138.4, 138.2, 138.0, 137.9, 128.4, 128.3, 128.1, 127.9, 127.8, 127.7, 127.6, 98.4, 91.0, 84.6, 81.0, 75.9, 75.6, 75.0, 74.9, 73.4, 68.2, 53.4.

General procedures for glycosylation:

A solution of 2,3,4,6-tetra-*O*-benzyl-D-glucopyranosyl trichloroacetimidate (**1aa**) (110 mg, 0.16 mmol, 1 equiv.) and acceptor, non-sugar **3a** (25 mg, 0.24 mmol, 1.5 equiv.) and sugar **3b** (42 mg, 0.16 mmol, 1.0 equiv.) in freshly dried CH_2Cl_2 were stirred at room temperature for 5 min. The reaction mixture was cooled to –10°C and further stirred for 5 min. To this reaction mixture activator BCF (tris(pentafluorophenyl)borane) (0.1 equiv.) was added and stirred for 1.5 h at the same temperature. After the completion of reaction through TLC monitoring, quenched using Et_3N (0.1 mL) and diluted with CH_2Cl_2. The organic layer was washed with brine and dried over anhydrous Na_2SO_4. The combined organic layer was evaporated under reduced pressure and residue was purified by column chromatography (SiO_2, hexane:ethyl acetate) to provide glycosylated product **4a** (92%) and **4b** (84%).

*Benzyl 2,3,4,6-tetra-O-Benzyl-β,α-D-glucopyranoside (**4a**):* The compound **4a** was prepared using the above general glycosylation procedure. The crude product was purified over silica gel column chromatography by using hexane:ethyl acetate (90:10) as eluent to provide **4a** as white solid (93 mg, 92% yield); R_f = 0.4 (10% EtOAc/hexane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.5–7.30 (m, 23H), 7.25 (dd, *J* 7.4, 1.8 Hz, 2H), 5.11–4.98 (m, 4H), 4.89 (dd, *J* 19.1, 10.9 Hz, 2H), 4.83–4.72 (m, 2H), 4.69 (d, *J* 21.9 Hz, 1H), 4.62 (dd, *J* 16.6, 5.0 Hz, 2H), 3.85 (dd, *J* 10.8, 1.9 Hz, 1H), 3.79 (dd, *J* 10.8, 4.8 Hz, 1H), 3.76–3.67 (m, 2H), 3.62 (t, *J* 8.3 Hz, 1H), 3.59–3.53 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 138.6, 138.4, 138.2, 138.2, 137.5, 128.4, 128.4, 128.4, 128.4, 128.2, 128.0, 128.0, 127.9, 127.8, 127.8, 127.7, 127.7, 127.6, 102.6, 84.8, 82.3, 77.9, 75.7, 75.0, 74.9, 74.9, 73.5, 71.2, 69.0; HRMS: Calcd. for $C_{41}H_{42}O_6$ $[M+H]^+$: 630.2981, Obser. 630.2978.

*2,3,4,6-Tetra-O-benzyl-β,α-D-glucopyranosyl-(1→6)-1,2:3,4-di-O-isopropylidene-α-D-galactopyranoside (**4b**):* The compound **4b** was prepared using the above general glycosylation procedure. The crude product was purified over silica gel column chromatography by using hexane:ethyl acetate (85:15) as eluent to provide **4b** as colourless viscous oil (106 mg, 84% yield); R_f = 0.3 (18% EtOAc/hexane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.47–7.42 (m, 2H), 7.38–7.28 (m, 16H), 7.16 (dd, *J* 7.1, 2.0 Hz, 2H), 5.59 (d, *J* 5.0 Hz, 1H), 5.03 (dd, *J* 48.6, 11.1 Hz, 2H), 4.86–4.71 (m, 3H), 4.66–4.60 (m, 2H), 4.58–4.46 (m, 3H), 4.34 (dd, *J* 5.0, 2.4 Hz, 1H), 4.27 (dd, *J* 7.9, 1.7 Hz, 1H), 4.19 (dd, *J* 10.7, 3.6 Hz, 1H), 4.12 (dd, *J* 5.8, 1.7 Hz, 1H), 3.79–3.71 (m, 3H), 3.69–3.60 (m, 2H), 3.53–3.43 (m, 2H), 1.53 (s, 3H), 1.48 (s, 3H), 1.34 (d, *J* 2.0 Hz, 6H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 138.7, 138.1, 138.1, 128.6, 128.3, 128.3, 128.3, 128.2, 127.9, 127.8, 127.8, 127.7, 127.6, 127.5, 127.4, 109.3, 108.5, 104.4, 96.4, 84.5, 81.6, 77.7, 75.6, 74.9, 74.7, 74.3, 73.5, 71.4, 70.8, 70.5, 69.7, 68.8, 67.3, 26.0, 26.0, 25.0, 24.4; Calcd. for $C_{46}H_{54}O_{11}$ $[M+H]^+$: 782.3666, Obser. 782.3662.

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