Organic & Biomolecular Chemistry

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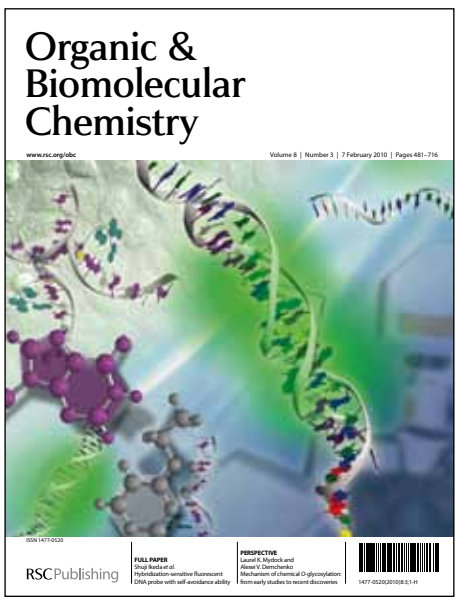

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ARTICLE TYPE

Regioselective azidotrimethylsilylation of carbohydrates and applications thereof

Mallikharjuna Rao L,[a] Syed Khalid Yousuf,[a] Debaraj Mukherjee,[a] Subhash Chandra Taneja[a*]

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Azidotrimethylsilylation of carbohydrates (monosaccharides and disaccharides) has been achieved in high yields under Mitsunobu conditions. The azidation of carbohydrates is affected at 0 °C essentially only at the primary alcoholic position in mono, di- and triols in protected/unprotected glycosides, whereas the remaining secondary hydroxyl groups got silylated. Surprisingly, no azidation was observed in the secondary hydroxyls in all the carbohydrate substrates. Applications of the methodology for the synthesis of aminosugars, triazoles and azasugars are reported.

Organic azides are among the most versatile functional groups in organic synthesis. They have fascinated the chemists ever since their discovery.[1] Besides their use in dipolar cycloadditions,[2] which clearly contributed to the renaissance of azide chemistry, they are the excellent reaction partners for a wide variety of transformations.[3] They act as precursors of highly reactive intermediates such as nitrenes and nitrenium ions, as well as more common and ubiquitous functional groups such as amines, aziridines, triazoles etc.[1] Although, among the most reactive functional groups, azides are often completely inert, at least from a kinetic point of view. In this context, carbohydrates bearing azido functions have emerged as attractive intermediates, bringing forth the 'click' adducts with their intrinsic properties (polarity, solubility, biocompatibility, biodegradability including biological role etc.) or for serving as scaffolds in drug discovery studies.[4] The reduction of azido carbohydrates could also give an access to new aminoglycosides,[5] an important class of biologically active compounds. Recently, Seeberger *et al.*[6] demonstrated the compatibility of the azido group during alkene metathesis of saccharides, thus exploited their use as protecting groups in carbohydrate chemistry. In addition to their chemical importance, biological utilisation of carbohydrate azides is remarkable. This can be supported by the use of AZT against AIDS and the use of azides in receptor compounds during photo affinity labelling.[7]

Furthermore, O-silylation could be the method of choice for protecting sugar hydroxyl groups in a complex synthetic sequence, because de-silylation can be effected selectively in the presence of other ether protecting groups. Silyl ethers of sugar derivatives can be easily converted into their formates using either PPh_3/CBr_4 in $HCOOEt/H_2O$[8] or Vilsmeier reagents.[9] Wang *et al.* utilized silylethers of monosaccharide building blocks as precursors for regioselective one-pot glycosylation.[10]

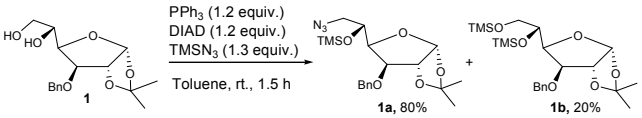
In carbohydrate chemistry, several methods of the synthesis of glycosyl azides have been explored, i.e. reactions of glycosyl halides with metal azides or tetramethylguanidinium azide under homogeneous conditions or by using phase transfer catalysts[11] of glycosyl esters with trimethylsilyl azide in the presence of a Lewis acid catalyst;[12] reacting cyclic 1,2-sulfite sugar derivatives[13] and thiocarbonate ring opening with NaN_3.[14] The selective azidation of the terminal hydroxyl group in monosaccharides for the synthesis of 6-deoxy-6-azido-2,3,4-tri-O-trimethylsilyl ethers involves multiple reaction steps i.e. tosylation of primary -OH group, base mediated silylation of secondary -OH groups by TMSCl followed by steroselective nucleophilic substitution of *O*-tosyl group by NaN_3.[15] Thus, the synthesis of azido derivatives of carbohydrates is not a trivial task and problems are frequently encountered because of the harsh experimental conditions such as the requirement of higher temperatures.

During the recent past one pot tandem reactions,[16] wherein more than one useful transformation can be carried out under the same reaction conditions without adding additional reagents and catalysts, have emerged as a powerful tool to achieve synthetic targets. Hence, in continuance of our recent efforts towards the development of one pot reaction strategies in carbohydrate chemistry,[17] we herein disclose one pot regioselective tandem azidotrimethylsilylation of sugars using $TMSN_3$ as a source of counter ions under Mitsunobu conditions. Although, regioselective and stereospecific azidotrimethylsilylation of 1,2- and 1,3-diols by $TMSN_3$ is reported under Mitsunobu conditions [18] there is no systematic study of this reaction on unprotected and protected carbohydrates except a few example of protected monosaccharides.[18b] Therefore, recognizing the huge importance of azide and silyl protecting groups in carbohydrate chemistry, we envisaged the exploitation of $TMSN_3$ under Mitsunobu conditions for tandem azidotrimethylsilylation of carbohydrate monosaccharides.

***Corresponding Author**. Tel.:+91-191-2569000; fax: +91-191-2569111; e-mail: sctaneja@iiim.ac.in,,*

[a]NPC(Microbes), CSIR- Indian Institute of Integrative Medicine, Canal Road Jammu Tawi, India-180001.

Initially, acetonide protected glucofuranoside **1** was selected as a model substrate to evaluate the efficacy of azidosilylation using $TMSN_3$ under different experimental conditions (Scheme 1). The reaction of **1** with $TMSN_3$ (1.3 equiv.), DIAD (1.2 equiv.) and TPP (1.2 equiv.) at room temperature was completed in 1.5 h affording a mixture of two products **1a** (80%) and **1b** (20%) (Scheme 1).



Scheme 1. Reaction of glucofuranoside **1** with $TMSN_3$

The major product **1a** was identified as 6-azido-6-deoxy-3-*O*-benzyl-5-*O*-trimethylsilyl-1,2-acetonideglucofuranoside, while **1b** was identified as persilylated product on the basis of NMR and IR spectral data. The upfield shift of CH_2 (δ, 55.1 ppm) in the ^{13}C NMR of **1a** indicated the azidation at primary hydroxyl group. The formation of **1a** can be easily explained by conventional reaction pathway through the formation of silyloxyphosphonium ion intermediate followed by nucleophilic attack by azide ion at less hindered terminal carbon (Fig. 1).[18a]

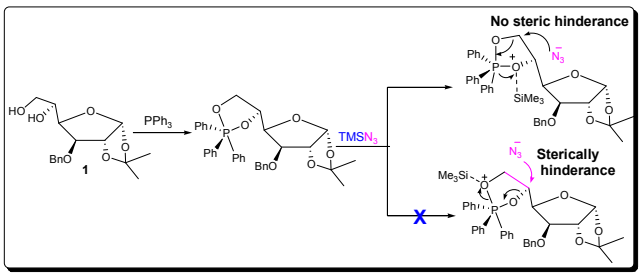


Fig.1. Explanation for regioselectivity

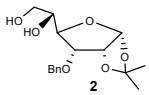
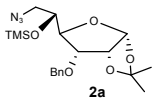
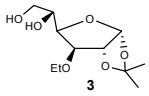
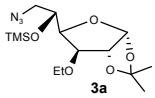
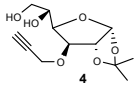
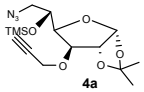
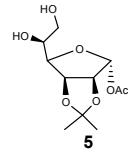
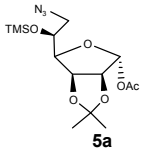
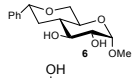
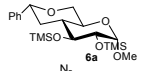
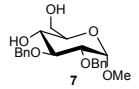
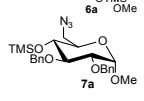
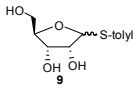
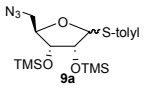
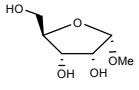
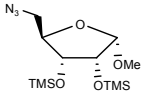
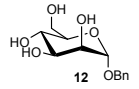
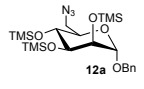
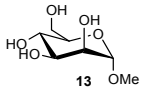
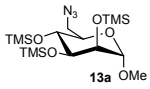
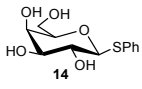
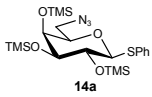
In order to obtain **1a** as the sole product, the substitution of DIAD with DEAD or DBAD under varied reaction conditions (Table 1) did not make any difference in the pattern of product formation. However, using DIAD as oxidiser and toluene as a solvent (Table 1, entries **7**) at lower temperature (0 °C), there was a marked change in the product distribution and **1a** was obtained almost as an exclusive product.

Table 1: Optimization of reaction conditions

Entry	Phosphine activator[a]	Solvent[b]	Temp. (°C)	Time (h)	Yield[c]% (**1a:1b**)[d]
1	DIAD	Toluene	rt.	1.5	60 (4:1)
2	DEAD	Toluene	rt.	3.0	75(3:2)
3	DBAD	Toluene	rt.	2.0	70(3:2)
4	DIAD	DMF	rt.	4.0	50(4:1)
5	DIAD	THF	rt.	2.5	62(7:3)
6	DIAD	DCM	rt.	2.5	60(7:3)
7	DIAD	Toluene	0	1.5	95(19:1)
8	DIAD	Toluene	60	1.0	0:0*
9	DIAD	Toluene	-10	5.0	94(19:1)

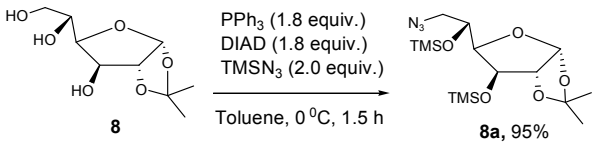
[a] In all the cases 1.2 equiv. were used. [b] 5 mL/100 mg of substrate. [c] Isolated yield of 1a. [d] Characterized through spectroscopic analysis. *Only primary azidation was observed.

Table 2. Reaction of different carbohydrates with $TMSN_3$ under Mitsunobu conditions

Entry	Substrate	Reagents in equiv. PPh_3/DIAD /$TMSN_3$	Product[a]	Yield[b] %
1		1.2/1.2/1.3		95
2		-do-		87
3		-do-		88
4		-do-		92
5		-do-		72
6		-do-		89
7		1.8/1.8/2.0		82*
8		-do-		81
9		2.4/2.4/2.6		89
10		-do-		90
11		-do-		87

[a]Identified by spectroscopic analysis. [b]Isolated yield after column chromatography. * β :α = >99:1.

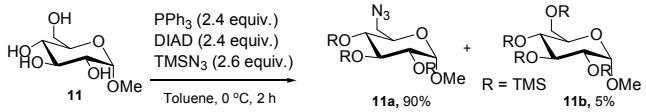
At higher temperature 60 °C, only primary azidation was observed probably by deprotection of silyl group mediated by the basic nature of side products. Following optimization of the reaction conditions, the scope of the reaction was explored on a panel of vicinal 1,2-sugar diols (Table 2, compounds **2**-**6**) and 1,3-diol (Table 2, compound 7). In all the substrates, the transformations proceeded smoothly leading to the formation of the azidotrimethylsilylated products in good to excellent yields except with **6** where only the persilylated product was obtained. From these examples, it may be construed that for the



Scheme 2. Reaction of 1,2-isopropylidene-α-D-glucofuranose with $TMSN_3$

azidotrimethylsilylation of sugars, the presence of a free primary hydroxyl group is an essential requirement. Next, we extended this study to tri-hydroxy sugar derivatives. Thus, 1,2-protected glucofuranoside (**8**) was allowed to react with $TMSN_3$ under the standardized reaction conditions to afford **8a** (95%) as the sole product (Scheme 2). It was observed that 2 equiv. of $TMSN_3$ under standardized reaction conditions was sufficient to afford the desired product. The regioselectivity of the reaction was high as analyzed from the spectroscopic data. Reaction of other tri-hydroxy compounds (Table 2, entries **7**, **8**) under optimized conditions also proceeded smoothly, affording the primary azidotrimethylsilylated products in good to excellent yields.

The importance and versatility of the reagent system in unprotected carbohydrates became evident, when the reaction of methyl-α-D-glucopyranoside (**11**) under the optimized reaction conditions was studied. As expected the reaction proceeded with high regioselectivity, leading to the formation of product **11a** in 90% yield along with the formation of small amounts of **11b** (5%) as a side product (Scheme 3).

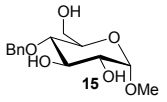
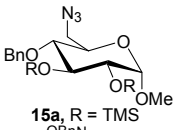
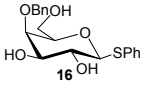
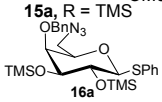
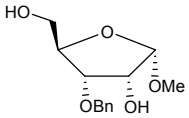
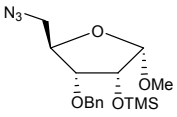
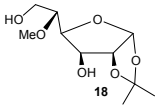
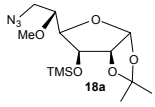
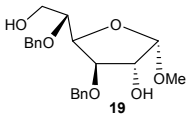
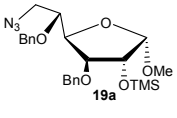
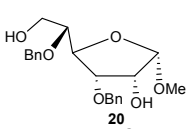
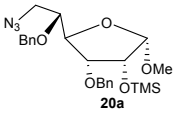
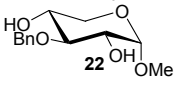
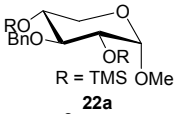
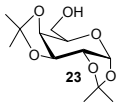
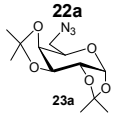
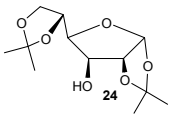
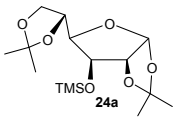


Scheme 3. Reaction of methyl-α-D-glucopyranoside with $TMSN_3$

Similar results were obtained with benzyl- or methyl-α-mannosides and thio-β-galactoside (Table 2, entries **9-11**). The stereochemistry at the anomeric centre hardly affects the regioselectivity or rate of the reaction.

Bittman *et al*[18] have explained the regioselective and stereosepecific azidation of 1,2- and 1,3- diols by $TMSN_3$ via Mitsunobu reaction. While working with 1,4-diol, the authors ended up with a cyclic ether (furan). In the case of carbohydrates, there are no other reports related to the reactions of 1,4- and 1,5-diols with Mitsunobu reagent system. Therefore, to study the behaviour of 1,4-sugar diols, methyl 4-*O*-benzyl–α-D-glucopyranoside (**15**) was subjected to react with $TMSN_3$ under the standardised reaction conditions. Predictably, **15** was converted exclusively to the 6-azido-2,3-di-*O*-silyl derivative **15a** (Table 3**,** entry **1**). Similar results were obtained from thio-4-*O*-benzyl-α-D-galactopyranoside (**16**) leading to the formation of azidosilyl derivative **16a** (Table 3**,** entry **2**). Furthermore, the reaction of furano-sugar derivatives methyl-3-*O*-benzyl-α-D-ribofuanoside (**17**) and methyl-5-*O*-methyl-1,2-*O*-(1-methylethylidene)-α-D-glucofuranose (**18**) afforded the azidotrimethylsilylated product **17a** and **18a** in almost quantitative yield **(**Table 3**,** entries **3, 4)**. Encouraged by the results, next we studied the reaction of 1,5-sugar diols i.e. methyl 5,3-di-*O*-benzyl-α-D-glucofuranose (**19**) and methyl-5,3-di-*O*-benzyl-α-D-allofuranose (**20**) under the optimized reaction conditions. In 1,5-sugar diols too**,** under stipulated reaction conditions regioslective azidation occurred at the primary

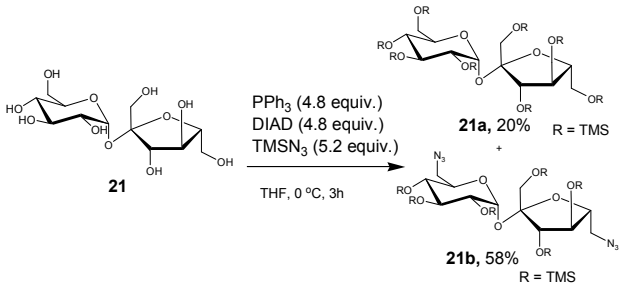
Table 3. Reaction of 1,4, 1,5- diols, primary and secondary hydroxyls with $TMSN_3$ under Mitsunobu conditions

Entry	Substrate	Reagents in equiv. PPh_3/DIAD/ $TMSN_3$	Product[a]	Yield[b] %
1		1.8/1.8/2.0		65
2		-do-		68
3		-1.2/1.2/1.3-		90
4		-do-		75
5		-do-		70
6		-do-		68*
7		-do-		80
8		1.0/1.0/1.0		67*
9		1.0/1.0/1.0		85

[a]Identified by spectroscopic analysis. [b]Isolated yield after column chromatography. *20% of silylated product was also formed.

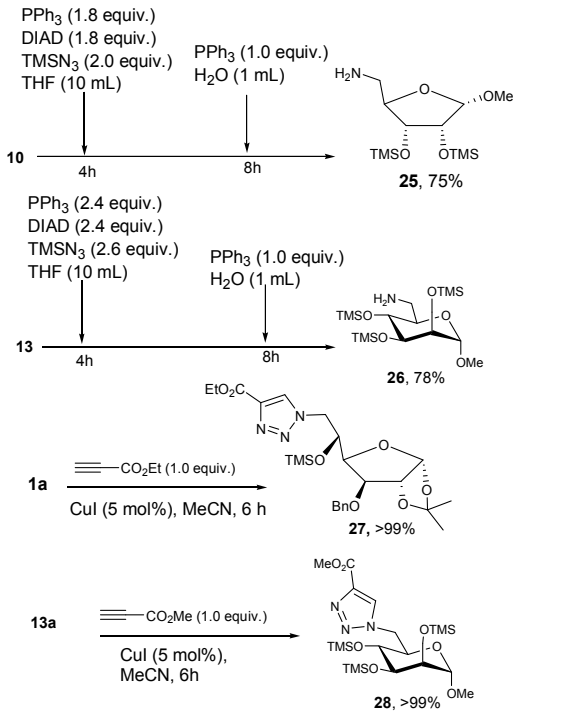
hydroxyl group leading to the formation of azidotrimethylsilylated product **19a** (70%) and **20a** (68%) **(**Table 3**,** entries **5, 6)** respectively. The reagent system was successfully applied to disaccharide sucrose (**21**) with three free primary hydroxyl groups. It was found that the reaction proceeded smoothly leading to the formation of diazido derivative **21b** as the major product (58%) along with the formation of of persilylated compound **21a** (20%) (Scheme 4). The regioselectivity of the azidation was determined through 2D NMR analysis.

Contrary to the literature reports[18a] of azidosilylation of 1,2- and 1,3-diols, the formation of five and six membered cyclic phosphonium ions and the concomitant nucleophilic attack from the less hindered side may easily explain the regioselectivity of



Scheme 4. Reaction of sucrose (**21**) with $TMSN_3$

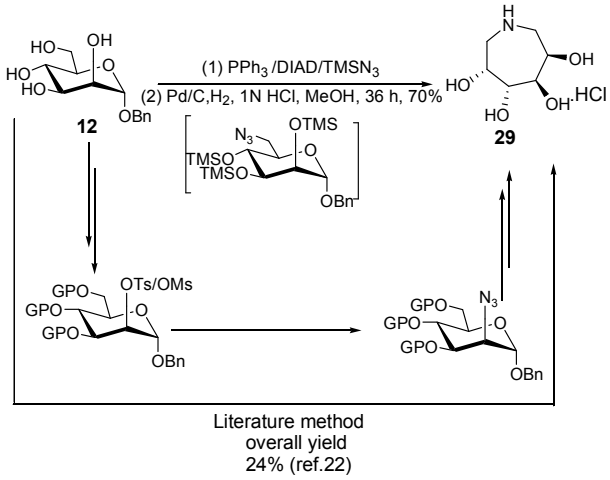
azidosilylation. In case of normal 1,2- and 1,3-diols,[18a] the attack of the nucleophile at the secondary position is due to inductive effects which largely overcome steric hindrance. However, in 1,4- and 1,5- diols, the formation of the cyclic phosphonium ion intermediate seems to be less favoured due to many factors including steric hindrance. Thus, the regioselectivity of 1,4- and 1,5- diols may possibly be rationalised by the stereoelectronic factors or on the basis of reactivities of the primary and the secondary hydroxyl groups. In general primary hydroxyls groups are more reactive than the secondary ones, whereas $TMSN_3$ is a weak nucleophile, therefore, the azidation of the primary hydroxyls groups is favoured. In other words, failure of azidation at secondary hydroxyl groups may be assigned to their inability to generate oxophosphonium ion in carbohydrates. This observation was substantiated by reacting methyl-3-*O*-benzyl-α-D-xylopyranoside (**22**) with $TMSN_3$ under standardised reaction conditions. The formation of persilylated product **22a** (Table 3, entry **7**) was in accordance to the proposed explanation on the basis of the reactivity of hydroxyl groups. Further, as expected the reaction of diacetonide galactopyranoside **23** (Table 3, entry **8**) and diacetonide glucofuranoside **24** (Table 3, entry **9**) also afforded the corresponding azido compound **23a** (67%) and silylated compound **24a** (85%) respectively. After establishing one pot tandem azidotrimethylsilylation methodology in sugar diols, triols, unprotected glycosides and disaccharides, we exploited the methodology in the synthesis of some of the chemically/medicinally useful compounds.



Scheme 5. Synthesis of aminosugars and triazoles using the one-pot strategy

Due to the huge biological importance of amino sugars, we initially tried one-pot amino-silylation of methyl-α-D-ribofuranoside (**10**) and methyl-α-D- mannopyranoside (**13**) under Staudinger's conditions[19] and successfully achieved the synthesis of 5-deoxy-5-amino-2,3-trimethylsilyloxy methyl-α-D-ribofuranoside (**25**) and 6-deoxy-6-amino-2,3,4-trimethylsilyloxy methyl-α-D-mannopyranoside (**26**) respectively (Scheme-5). Similarly, 2,3-dipolar cycloadditions[20] (Click reaction) to prepare 1,4-triazole derivatives **27** and **28** were equally successful using **1a** and **13a** as the starting material (Scheme 5). In the ^{1}HNMR spectra of **27** and **28**, the downfield shift of azide protons indicates the azide protons were at primary position.

In recent past the synthesis of aza sugars has gained much attention due to their biological importance,[21] we therefore attempted the synthesis of tetrahydroxy azepane **29** using the current methodology (Scheme 6). Thus benzyl-α-D-mannopyranoside (**12**) was subjected to one pot azidosilylation followed by reduction and reductive cyclisation using Pd/C. As expected, azepane **29** was synthesized in 70% yield. The literature method employed a longer route for its synthesis with 24% overall yield.[22] The ^{1}HNMR of compound **29** was in complete agreement with literature data.[22]



Scheme 6. Synthesis of mannoazepane **29**.

In conclusion, we have demonstrated the efficacy of a methodology for the regioselective tandem azidotrimethylsilylation of carbohydrates under Mitsunobu conditions. It was also established that the presence of a free primary hydroxyl function in 1,2 and 1,3, 1,4, 1,5 diols and protected/unprotected sugars is essential for azidation. Versatility of the current process for the synthesis of aminoglycoside, triazole and aza sugar such as tetrahydroxy azepane is also disclosed. The methodology is facile and may find wider applications in carbohydrate chemistry. Further applications of this methodology for the synthesis of useful aza sugars and N-glycosides are in progress and will be reported in due course of

time.

Experimental section

General information

^{1}H and ^{13}C NMR spectra were recorded on Bruker 200, 400 and 500 MHz spectrometers (Model No. D 205/52-2382, Avance 500) with TMS as the internal standard. Chemical shifts are expressed in parts per million (δ ppm). MS were recorded on Waters LC Mass spectrometer (Model No. Symapt MS). Optical rotations were measured on Perkin Elmer (Model No. 241). Silica gel coated aluminium plates were used for TLC.Elemental analyses were performed on Vario Elementar (Model No. EL). Reagents and solvents used were mostly of LR grade.

General procedure (1) for the azidotrimethylsilylation of diols. DIAD (1.3 mmol, 236 µL) was injected at 0 °C to a solution of a diol (1.0 mmol) and Ph_3P (314 mg, 1.2 mmol) (both thoroughly dried in inert atmosphere) in 18 mL of dry toluene. The yellow reaction mixture was stirred at this temperature for 30 minutes under nitrogen followed by the addition of Me_3SiN_3 (1.3 mmol, 155 µL). The reaction mixture was further stirred at the same temperature for 3 h before allowed to warm to room temperature. The completion of the reaction was monitored by TLC. Evaporation of the solvent yielded a crude product, which was dissolved in CH_2Cl_2 and passed through a pad of silica gel in a sintered glass funnel to remove Ph_3PO and salts. The pad was washed with a mixture of hexanes-EtOAc (usually 6/1) depending on the polarity of the products. The crude products were purified by silica gel chromatography.

General procedure (2) for the azidotrimethylsilylation of triols. DIAD (1.8 mmol, 354 µL) was injected at 0 °C to a solution of a triol (1.0 mmol) and Ph_3P (472 mg, 1.8 mmol) (both thoroughly dried in inert atmosphere) in 25 mL of dry toluene. The yellow reaction mixture was stirred at this temperature for 30 minutes under nitrogen followed by the addition of Me_3SiN_3 (2.0 mmol, 239 µL). The reaction mixture was further stirred at the same temperature for 3 h before allowed to warm to room temperature. The completion of the reaction was monitored by TLC. The crude product after evaporation of the solvent was dissolved in CH_2Cl_2 and passed through a pad of silica gel in a sintered glass funnel to remove Ph_3PO and salts. The pad was washed with a mixture of hexanes-EtOAc (usually 6/1) depending on the polarity of the products. The crude products were purified by silica gel chromatography.

General procedure (3) for the azidosilylation of unprotected glycosides. DIAD (2.4 mmol, 472 µL) was injected at 0 °C to a solution of an unprotected glycoside (1.0 mmol) and Ph_3P (628 mg, 2.4 mmol) in 30 mL of toluene as described above. The reaction mixture was stirred for 30 minutes under nitrogen followed by the addition of Me_3SiN_3 (2.6 mmol, 311 µL). The reaction mixture was further stirred at the same temperature for 3 h before allowed to warm to room temperature. The completion of the reaction was monitored by TLC. The crude product after evaporation of the solvent was dissolved in CH_2Cl_2 and passed through a pad of silica gel in a sintered glass funnel to remove Ph_3PO and salts. The pad was washed with a mixture of hexanes-EtOAc (usually 6/1) depending on the polarity of the products. The crude products were purified by silica gel chromatography.

6-Azido-3-*O*-benzyl-6-deoxy-l,2-*O*-(l-methylethylidene)-5-*O*-trimethylsilyl-α-D-glucofuranose (1a). It was prepared by the general procedure **1** using 1.0 mmol (310 mg) of **1** to yield the desired product **1a** (94%, 382 mg) as oily liquid. IR ($CHCl_3$): 3032, 2957, 2110, 1290, 1253, 1026, 845 cm^{-1}. $[\alpha]^{20}_D$ = -35.0 (c, 1.0, $CHCl_3$). ^{1}H NMR (200MHz, $CDCl_3$), δ; 7.28–7.17 (m, 5H), 5.75 (d, *J* = 3.68 Hz, 1H), 4.58 (d, *J* = 13.2 Hz, 1H), 4.47-4.39 (m, 2H), 4.06 (bs, 2H), 3.92 (s, 1H), 3.49 (dd, *J* = 2.1, 12.3 Hz, 1H, H-6a/b), 3.30 (ddd, *J* = 1.9, 12.4 Hz, 1H, H-6a/b), 1.39 (s, 3H), 1.33 (s, 3H), -4.818 (s, 9H). ^{13}C NMR (50 MHz, $CDCl_3$), δ; 137.4, 128.5, 128.4, 128.3, 127.8, 127.3, 111.9, 105.0, 81.4, 81.2, 80.6, 71.6, 68.5, 55.1, 26.8, 26.3, 0.66. ESI-MS; 430 $(M+Na)^+$; Anal. Cal. For $C_{19}H_{29}N_3O_5Si$; C, 56.00; H, 7.17; N, 10.31; Found C, 55.92; H, 7.02; N, 10.21.

6-Azido-3-*O*-benzyl-6-deoxy-l,2-*O*-(l-methylethylidene)-5-*O*-trimethylsilyl-α-D-allofuranose (2a). Prepared by the general procedure **1** using 1.0 mmol (310 mg) of **2** to yield the desired product **2a** (95%, 386 mg) as oily liquid. IR ($CHCl_3$): 3033, 2967, 2101, 1292, 1253, 1026, 845, 740 cm^{-1}. $[\alpha]^{20}_D$ = -65.0 (c, 1.0, $CHCl_3$). ^{1}H NMR (500MHz, $CDCl_3$), δ; 7.25-7.14 (m, 5H), 5.75 (d, *J* = 3.5 Hz, 1H), 4.56 (d, *J* = 2.6 Hz, 1H), 4.45-4.43 (m, 2H), 4.05-4.03 (m, 2H), 3.93 (d, *J* = 8.6 Hz, 1H), 3.45 (d, *J* = 12.8 Hz, 1H, H-6a/b), 3.25 (dd, *J* = 11.1, 12.8 Hz, 1H, H-6a/b), 1.39 (s, 3H), 1.18 (s, 3H), 0.032 (s, 9H). ^{13}C NMR (50 MHz, $CDCl_3$), δ; 137.4, 128.5, 128.4, 127.8, 127.3, 127.2, 111.9, 105.0, 81.7, 81.3, 80.6, 71.6, 68.5, 55.1, 26.8, 26.3, 0.4 (3C). ESI-MS; 430 $(M+Na)^+$; Anal. Cal. for $C_{19}H_{29}N_3O_5Si$; C, 56.00; H, 7.17; N, 10.31; Found C, 55.92; H, 7.02; N, 10.21.

6-Azido-3-*O*-ethyl-6-deoxy-l,2-*O*-(l-methylethylidene)-5-*O*-trimethylsilyl-α-D-glucofuranose (3a). Prepared by the general procedure **1** using 1.0 mmol (248 mg) of **3** to yield the desired product **3a** (87%, 300 mg) as oily liquid. IR ($CHCl_3$): 2976, 2102, 1290, 1081, 843 cm^{-1}. $[\alpha]^{20}_D$ = -53.0 (c, 1.0, $CHCl_3$). ^{1}H NMR (500MHz, $CDCl_3$), δ; 5.67 (d, *J* = 3.7 Hz, 1H), 4.40 (d, *J* = 3.7 Hz, 1H), 3.94 (dd, *J* = 2.7, 6.1 Hz, 1H), 3.96-3.94 (m, 1H), 3.67 (d, *J* = 2.7 Hz, 1H), 3.52 (dd, *J* = 1.9, 5.1 Hz, 1H), 3.39 (dd, *J* = 2.3, 10.4 Hz, 1H), 3.29 (dd, *J* = 1.9, 5.1 Hz, 1H, H-6a/b), 3.17 (dd, *J* = 5.1, 7.6 Hz, 1H, H-6a/b), 1.32 (s, 3H), 1.14 (s, 3H), 1.05 (t, *J* =6.9 Hz, 3H), 0.006 (s, 9H). ^{13}C NMR (50 MHz, $CDCl_3$), δ ; 111.6, 104.6, 81.0, 80.9, 80.0, 66.8, 64.8, 53.0, 26.4, 26.1, 14.6, 0.21 (3C). ESI-MS; 368 $(M+Na)^+$; Anal. Cal. for $C_{14}H_{27}N_3O_5Si$; C, 48.67; H, 7.88; N, 12.16; Found C, 48.53; H, 7.76; N, 12.03.

6-Azido-3-*O*-propargyl-6-deoxy-l,2-*O*-(l-methylethylidene)-5-*O*-trimethylsilyl-α-D-glucofuranose (4a). Prepared by the general procedure **1** using 1.0 mmol (258 mg) of **4** to yield the desired product **4a** (88%, 312 mg) as oily liquid. IR ($CHCl_3$): 3300, 2957, 2104, 1252, 844, 669 cm^{-1}. $[\alpha]^{20}_D$ = -51.0 (c, 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$), δ; 5.84 (d, *J* = 4.0 Hz, 1H), 4.68 (d, *J* = 3.6 Hz, 1H), 4.23 (dd, *J* = 2.4, 5.6 Hz, 1H), 4.17 (dd, *J* = 2.8, 8.8 Hz, 1H), 4.10 (dd, *J* = 2.8, 4.8 Hz, 1H), 4.08 (d, *J* = 3.2 Hz, 2H), 3.55 (dd, *J* = 2.8, 12.8 Hz, 1H, H-6a/b), 3.34 (dd, *J* = 4.8, 12.8 Hz, 1H, H-6a/b), 2.48 (s, 1H), 1.49 (s, 3H), 1.30 (s, 3H), 0.178 (s, 9H). ^{13}C NMR (50MHz, $CDCl_3$), δ; 111.5, 104.4, 80.4, 80.2, 80.0, 78.2, 75.4, 67.8, 56.6, 54.4, 26.2, 25.8, -0.47 (3C). ESI-MS; 378 $(M+Na)^+$; Anal. Cal. for $C_{15}H_{25}N_3O_5Si$; C, 50.68; H, 7.09; N, 11.82; Found C, 50.51; H, 6.93; N, 11.70.

6-azido-6-deoxy-5-O-trimethylsilyl-2,3-*O*-(l-methylethylidene)-1-acetyl-α-D-mannofuranose (5a). Prepared by the general procedure **1** using 1.0 mmol (262 mg) of **5** to yield the desired product **5a** (92%, 330 mg) as oily liquid. IR ($CHCl_3$): 2959, 2102, 1231, 1053, 845 cm^{-1}. $[\alpha]^{20}_D$ = +25.0 (c,

1.0, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$), δ; 5.98 (bs, 1H), 4.60 (dd, *J* = 3.3, 6.8 Hz, 1H), 4.49 (d, *J* = 6.8 Hz, 1H), 3.95-3.93 (m, 1H), 3.88 (dd, *J* = 3.2, 8.9 Hz, 1H), 3.27 (dd, *J* = 2.5, 12.7 Hz, 1H, H-6a/b), 3.11 (dd, *J* = 5.0, 12.7 Hz, 1H, H-6a/b), 1.87 (s, 3H), 1.28 (s, 3H), 1.09 (s, 3H), -0.006 (s, 9H). ^{13}C NMR (50 MHz, $CDCl_3$), δ; 169.2, 112.7, 101.2, 84.7, 81.5, 78.9, 68.9, 54.8, 25.9, 24.6, 21.6, 0.23 (3C). ESI-MS; 382 $(M+Na)^+$; Anal. Cal. for $C_{14}H_{25}N_3O_6Si$; C, 46.78; H, 7.01; N, 11.69; Found C, 46.57; H, 6.92; N, 11.53.

Methyl 4,6-*O*-benzylidene-2,3-di-*O*-trimethylsilyl-α-D-glucopyranoside (6a). Prepared by the general procedure **1** using 1.0 mmol (282 mg) of **6** to yield the desired product **6a** (72%, 306 mg) as oily liquid. IR ($CHCl_3$): 3034, 2997, 1290, 1058cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$), δ; 7.32-7.30 (m, 2H), 7.20-7.16 (m, 3H), 5.33 (s, 1H), 4.45 (d, *J* = 3.7 Hz, 1H), 4.09 (dd, *J* = 4.7, 10.4 Hz, 1H), 3.78 (t, *J* = 8.9 Hz, 1H), 3.63-3.61 (m, 1H), 3.53 (t, *J* = 10.2 Hz, 1H), 3.44 (dd, *J* = 3.7, 8.7 Hz, 1 H), 3.25 (s, 3H), 3.23-3.21 (m, 1H), -0.01 (s, 9H), -0.07 (s, 9H). ^{13}C NMR (50 MHz, $CDCl_3$), δ; 137.0, 128.5, 128.4, 127.8, 127.7, 125.8, 101.3, 100.6, 81.7, 73.8, 71.4, 68.7, 62.0, 55.0, 0.5 (3C), 0.3 (3C). ESI-MS; 449 $(M+Na)^+$; Anal. Cal. For $C_{21}H_{36}O_5Si_2$; C, 56.30; H, 8.03; Found C, 56.21; H, 7.91.

Methyl 6-Azido-2,3-di-*O*-benzyl-6-deoxy-4-*O*-trimethylsilyl-α-D-glucopyranoside (7a). Prepared by the general procedure **2** using 1.0mmol (374 mg) of **7** to yield the desired product **7a** (89%, 419 mg) as oily liquid. IR ($CHCl_3$): 3032, 2098, 1252, 1053, 842cm^{-1}. $[\alpha]^{20}_D$ = +55.0 (c, 1.0, $CHCl_3$). ^1H NMR (400 MHz, $CDCl_3$), δ; 7.26-7.34 (m, 10H), 4.99 (d, *J* = 11.2 Hz, 1H), 4.73 (d, *J* = 11.2 Hz, 1H), 4.68 (bs, 1H), 4.59 (d, *J* = 2.0 Hz, 1H), 4.58 (d, *J* = 10.4 Hz, 1H), 3.75-3.70 (m, 2H), 3.54 (d, *J* = 9.2 Hz, 1H), 3.49 (dd, *J* = 3.6, 9.6 Hz, 1H), 3.45 (dd, *J* = 2.4, 12.8 Hz, 1H, H-6a/b), 3.39 (s, 3H, $-OCH_3$), 3.33 (dd, *J* = 5.6 12.8 Hz, 1H, H-6a/b), 0.094 (s, 9H). ^{13}C NMR (50 MHz, $CDCl_3$), δ; 138.3, 137.4, 127.8, 127.7, 127.6, 127.5, 127.4, 127.3, 126.9, 126.7, 126.6, 126.5, 97.3, 80.8, 79.6, 74.7, 72.7, 71.1, 70.4, 54.7, 50.7, -0.23 (3C). ESI-MS; 494 $(M+Na)^+$; Anal. Cal. for $C_{24}H_{33}N_3O_5Si$; C, 61.12; H, 7.05; N, 8.91; Found C, 61.02; H, 6.93; N, 8.70.

6-Azido-6-deoxy-l,2-*O*-(l-methylethylidene)-3,5-di-*O*-trimethylsilyl-α-D-glucofuranose (8a). Prepared by the general procedure **2** using 1.0 mmol (220 mg) of **8** to yield the desired product **8a** (95%, 369 mg) as oily liquid. IR ($CHCl_3$): 2962, 2100, 1253, 1058, 843 cm^{-1}. $[\alpha]^{20}_D$ = -15.0 (c, 1.0, $CHCl_3$). ^1H NMR (400MHz, $CDCl_3$), δ; 5.84 (d, *J* = 3.6 Hz, 1H), 4.40 (d, *J* = 3.6 Hz, 1H), 4.20 (d, *J* = 2.0 Hz, 1H), 4.10-4.04 (m, 2H), 3.55 (dd, J = 5.2, 12.4 Hz, 1H, H-6a/b), 3.42 (dd, *J* = 5.2, 8.0 Hz, 1H, H-6a/b), 1.47 (s, 3H), 1.30 (s, 3H), 0.185 (s, 9H), 0.176 (s, 9H). ^{13}C NMR (50 MHz, $CDCl_3$), δ; 111.9, 104.9, 84.4, 81.6, 75.2, 68.8, 54.9, 26.7, 26.3, 0.61 (3C), 0.46 (3C). ESI-MS; 412 $(M+Na)^+$; Anal. Cal. for $C_{15}H_{31}N_3O_5Si_2$; C, 46.24; H, 8.02; N, 10.79; Found C, 46.11; H, 7.93; N, 10.70.

Thio-*p*-toluoyl 5-azido-5-deoxy-2,3-di-*O*-trimethylsily-β-D-ribofuranoside (9a). Prepared by the general procedure 2 using 1.0 mmol (256 mg) of **9** to yield the desired product **9a** (82%, 348 mg) as oily liquid. IR ($CHCl_3$): 3034, 2957, 2108, 1253, 1088, 843cm^{-1}. $[\alpha]^{20}_D$ = = +43.0 (c, 1.0, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$), δ; 7.22-7.19 (m, 2H), 6.97-6.92 (m, 2H), 4.28 (d, *J* = 9.1 Hz, 1H), 3.71 (dd, *J* = 5.2, 11.4 Hz, 1H), 3.45-3.43 (m, 1H), 3.35-3.33 (m, 1H), 3.09 (dd, *J* = 10.4, 16.1Hz, 1H, H-5a/b), 3.01 (dd, *J* = 10.4, 11.4 Hz, 1H, H-5a/b), 2.16 (s, 3H), 0.04 (s, 9H), 0.006 (s, 9H). ^{13}C NMR (50MHz, $CDCl_3$), δ; 137.8, 132.7, 132.6, 130.2, 130.1, 130.0, 90.3, 73.1, 72.5, 70.5, 70.1, 21.2, 0.23 (3C), 0.16 (3C). ESI-MS; 448 $(M+Na)^+$; Anal. Cal. for $C_{17}H_{29}N_3O_3SSi_2$; C, 50.79; H, 7.34; N, 9.87; Found C, 50.34; H, 7.24; N, 9.70.

Methyl 5-azido-5-deoxy-2,3-di-*O*-trimethylsily-α-D-ribofuranoside (10a). Prepared by the general procedure **2** using 1.0 mmol (192 mg) of **10** to yield the desired product **10a** (81%, 292 mg) as oily liquid. IR ($CHCl_3$): 2954, 2106, 1255, 1056, 844 cm^{-1}. $[\alpha]^{20}_D$ = +37.0 (c, 1.0, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$), δ; 3.90 (t, *J* = 3.3, 1H), 3.62 (dd, *J* = 5.3, 11.6, 1H), 3.65-3.63 (m, 1H), 3.35 (s, 3H), 3.07 (d, *J* = 4.0 Hz, 1H), 3.06 (dd, *J* = 11.5, 13.6 Hz, 1H, H-6a/b), 3.03 (dd, *J* = 4.0, 11.5 Hz, 1H, H-6a/b), -0.015 (s, 9H), -0.044 (s, 9H). $^{13}CNMR$ (50 MHz, $CDCl_3$), δ; 104.7, 73.4, 70.6, 69.3, 66.6, 56.8, 0.29 (3C), 0.14 (3C). ESI-MS; 384 $(M+Na)^+$. Anal. Cal. For $C_{12}H_{27}N_3O_4Si_2$; C, 43.21; H, 8.16; N, 12.60; Found C, 43.02; H, 8.03; N, 12.49.

Methyl 6-azido-6-deoxy-2,3,4-tri-*O*-trimethylsilyl-α-D-glucopyranoside (11a). Prepared by the general procedure **3** using 1.0 mmol, (194 mg) of **11** to yield the desired product **11a** (90%, 391 mg) as oily liquid. IR ($CHCl_3$): 2958, 2099, 1253, 1057, 845cm^{-1}. $[\alpha]^{20}_D$ = +68.0 (c, 1.0, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$), δ; 4.46 (d, *J* = 3.6 Hz, 1H), 3.56-3.55 (m, 1H), 3.52 (dd, *J* = 2.4, 6.4 Hz, 1H), 3.32 (dd, *J* = 3.6, 13.2 Hz, 1H), 3.28 (dd, *J* = 2.4, 13.2 Hz, 1H), 3.24 (dd, *J* = 6.0, 9.6 Hz, 1H, H-6a/b), 3.21 (s, 3H, $-OCH_3$), 3.17 (dd, *J* = 6.0, 13.2 Hz, 1H, H-6a/b), 0.029 (s, 9H), -0.014 (s, 9H), -0.027 (s, 9H). ^{13}C NMR (50 MHz, $CDCl_3$), δ; 99.8, 74.8, 73.7, 73.0, 70.8, 54.5, 51.6, 0.98 (3C), 0.94 (3C), 0.68 (3C). ESI-MS; 458 $(M+Na)^+$; Anal. Cal. for $C_{16}H_{37}N_3O_5Si_3$; C, 44.10; H, 8.56; N, 9.64. Found C, 39.92; H, 8.43; N, 9.53.

Benzyl 6-azido-6-deoxy-2,3,4-tri-*O*-trimethylsilyl-α-D-mannopyranoside (12a). Prepared by the general procedure **3** using 1.0 mmol (270 mg) of **12** to yield the desired product **12a** (89%, 454 mg) as oily liquid. IR ($CHCl_3$): 3035, 2956, 2100, 1250, 1099, 842cm^{-1}. $[\alpha]^{20}_D$ = +46.0 (c, 1.0, $CHCl_3$). ^1H NMR (400 MHz, $CDCl_3$); δ; 7.22-7.15 (m, 5H), 4.61 (d, *J* = 12.0 Hz, 1H), 4.54 (d, *J* = 1.6 Hz, 1H), 4.38 (d, *J* = 12 Hz, 1H), 3.7 (d, *J* = 9.2 Hz, 1H), 3.67 (dd, *J* = 2.4, 4.0 Hz, 1H), 3.63 (dd, *J* = 2.4, 10 Hz, 1H), 3.59-3.57 (m, 1H), 3.26 (dd, *J* = 2.4, 12.8 Hz, 1H, H-6a/b), 3.19 (dd, *J* = 6.8, 12.8 Hz, 1H, H-6a/b), -0.009 (s, 9H), -0.024 (s, 9H), -0.04 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$), δ; 137.2, 127.6, 127.5, 127.4, 126.2, 126.1, 99.5, 73.2, 73.1, 72.1, 68.8, 68.5, 51.1, 0.46 (3C), 0.37 (3C), 0.34 (3C). ESI-MS; 534 $(M+Na)^+$; Anal. Cal. for $C_{22}H_{41}N_3O_5Si_3$; C, 51.63; H, 8.07; N, 8.21; Found C, 51.34; H, 7.89; N, 8.01.

Methyl 6-azido-6-deoxy-2,3,4-tri-*O*-trimethylsilyl-α-D-mannopyranoside (13a). Prepared by the general procedure 3 using 1.0 (194 mg) of **13** to yield the desired product **13a** (90%, 391 mg) as oily liquid. IR ($CHCl_3$): 2958, 2914, 2099, 1252, 1154, 1020, 840, 752 cm^{-1}. $[\alpha]^{20}_D$ = +73.0 (c, 1.0, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$), δ; 4.34 (bs, 1H), 3.68 (t, *J* = 9.0 Hz, 1H), 3.63 (d, *J* = 1.5 Hz, 1H), 3.57 (dd, *J* = 2.5, 8.8 Hz, 1H), 3.51-3.50 (m, 1H), 3.28 (dd, *J* = 2.1, 12.8 Hz, 1H, H-6a/b), 3.23 (s, 3H, $-OCH_3$), 3.19 (dd, *J* = 7.1, 12.8 Hz, 1H, H-6a/b), -0.021 (s, 9H), -0.034 (s, 9H), -0.096 (s, 9H). ^{13}C NMR (50 MHz, $CDCl_3$), δ; 101.4, 73.04, 73.02, 72.03, 68.7, 54.4, 51.0, 0.38 (3C), 0.24 (3C), 0.15 (3C). ESI-MS; 458 $(M+Na)^+$; Anal. Cal. for $C_{16}H_{37}N_3O_5Si_3$; C, 44.10; H, 8.56; N, 9.64; Found C, 44.01; H,

8.43; N, 9.50.

Thiophenyl 6-azido-6-deoxy-2,3,4-tri-*O*-trimethylsilyl-β-D-galactopyranoside 14a. Prepared by the general procedure **3** using 1.0 mmol (272 mg) of **14** to yield the desired product **14a** (87%, 446 mg) as oily liquid. IR ($CHCl_3$): 3061, 2956, 2109, 1251, 1146, 844, 746 cm^{-1}. $[\alpha]^{20}_D$ = +46.3 (c, 1.0, $CHCl_3$). ^1H NMR (400 MHz, $CDCl_3$), δ; 7.48-7.45 (m, 2H), 7.27-7.22 (m, 3H), 4.49 (d, *J* = 9.2 Hz, 1H), 3.54 (t, *J* = 0.8 Hz, 1H), 3.49 (dd, *J* = 8.0, 9.6 Hz, 1H), 3.43 (dd, *J* = 6.0, 11.2 Hz, 1H), 3.38 (d, *J* = 8.0 Hz, 1H), 3.28 (dd, *J* = 0.8, 1.6 Hz, 1H, H-6a/b), 3.26 (dd, *J* = 1.6, 5.6 Hz, 1H, H-6a/b), 0.196 (s, 9H), 0.146 (s, 9H), 0.11 (s, 9H). ^{13}C NMR (50 MHz, $CDCl_3$), δ; 133.5, 130.8, 130.7, 128.7, 128.6, 127.3, 89.3, 78.0, 74.5, 64.1, 51.8, 0.88 (3C), 0.63 (3C), 0.45 (3C). ESI-MS; 536. $(M+Na)^+$; Anal. Cal. For $C_{21}H_{39}N_3O_4SSi_3$; 49.08; H, 7.65; N, 8.18; .Found C, 39.91; H, 7.51; N, 8.01.

Metyl 6-azido-6-deoxy-4-*O*-benzyl-2,3-di-*O*-trimethylsilyl-α-D-glucopyranoside (15a). It was prepared by the general procedure **2** using 0.52 mmol (150 mg) of **15** to yield the desired product **15a** (65%, 160 mg) as oily liquid. IR ($CHCl_3$): 3035, 2985, 2109, 1290, 1057, 846, 754 cm^{-1}. $[\alpha]^{20}_D$ = +130.0 (c, 1.0, $CHCl_3$). ^1H NMR (400 MHz, $CDCl_3$) δ; 7.18-7.11 (m, 5H), 4.74 (d, *J* =11.6 Hz, 1H), 4.45 (d, *J* = 3.6 Hz, 1H), 4.35 (d, *J* = 1.6Hz, 1H), 3.75 (dd, *J* = 3.6, 8.8 Hz, 1H), 3.56 (ddd, *J* =2.4, 6.0, 10.0, Hz, 1H), 3.36 (dd, *J* = 3.6, 9.2Hz, 1H), 3.20 (s, 3H, -OCH_3), 3.16 (dd, *J* = 7.2, 11.6 Hz, 1H, H-6a/b), 3.11 (dd, *J* = 5.6, 7.2 Hz, 1H, H6a/b), -0.02 (s, 9H), -0.09 (s, 9H). ^{13}C NMR (125MHz, $CDCl_3$) δ; 137.5, 128.1, 128.0, 127.8, 127.3, 127.0, 99.5, 79.2, 74.8, 74.3, 73.4, 69.3, 54.7, 52.9, 0.51 (3C), 0.46 (3C). ESI-MS; 476 $(M+Na)^+$; Anal. Cal. For; $C_{20}H_{35}N_3O_5Si_2$; C, 52.95; H, 7.78; N, 9.26; Found C, 52.83; H, 7.65; N, 9.17.

Thiophenyl 6-azido-6-deoxy-4-*O*-benzyl-2,3-di-*O*-trimethylsilyl-β-D-galactopyranoside (16a). It was prepared by the general procedure **2** using 0.27 mmol (100 mg) of **16** to yield the desired product **16a** (68%, 99.7 mg) as a syrapy liquid. IR ($CHCl_3$): 2987, 2105, 1290, 1049 cm^{-1}. $[\alpha]^{20}_D$ = +43.5 (c, 1.0, $CHCl_3$). ^{1}HNMR (400 MHz, $CDCl_3$) δ; 7.31-7.28 (m, 2H), 7.16-7.10 (m, 5H), 7.09-7.02 (m, 3H), 4.80 (d, *J* = 11.2 Hz, 1H), 4.40 (s, 1H), 4.36 (d, *J* = 9.6 Hz, 1H), 3.82 (t, *J* = 8.8 Hz, 1H), 3.44-3.42 (m, 1H), 3.41-3.40 (m, 1H), 3.36 (d, *J* = 6.8 Hz, 1H), 3.33 (dd, *J* = 0.8, 4.8 Hz, 1H, H-6a/b), 2.99 (dd, *J* = 4.8, 11.6 Hz, 1H, H6a/b), 0.01(s, 9H), -0.04 (s, 9H). ^{13}C NMR (125 MHz, $CDCl_3$) δ; 138.4, 134.6, 131.4, 131.1, 129.1, 128.7, 128.5, 128.2, 128.0, 127.9, 127.3, 126.9, 89.8, 77.7, 77.3, 77.0, 74.9, 71.1, 51.3, 1.1 (3C), 0.40 (3C). ESI-MS; 554 $(M+Na)^+$; Anal. Cal. For $C_{25}H_{37}N_3O_4SSi_2$; C, 56.46; H, 7.01; N, 7.90; Found C, 56.34; H, 6.90; N, 7.79.

Methyl 5-azido-5-deoxy-3-*O*-benzyl-2-*O*-trimethylsilyl-α-D-ribofuranoside (17a). It was prepared by the general procedure **1** using 0.787 mmol (200 mg) of **17** to yield the desired product **17a** (90%, 248 mg) as oily liquid. IR ($CHCl_3$): 3037, 2927, 2101, 1252, 1158, 1036,847, 765cm^{-1}. $[\alpha]^{20}_D$ = +31.6 (c, 1.0, $CHCl_3$). ^1H NMR, (400 MHz, $CDCl_3$) δ; 7.19-7.12 (m, 5H), 4.55 (s, 1H), 4.45 (d, *J* =11.6 Hz, 1H), 4.24 (d, *J* = 11.6 Hz, 1H), 4.06 (m, 1H), 3.95 (d, *J* = 4.0 Hz, 1H), 3.74 (dd, *J* =4.0, 7.6 Hz, 1H), 3.25 (dd, *J* = 3.2, 13.2 Hz, 1H, H-5a/b), 3.20 (s, 3H, -OCH_3), 3.03 (dd, *J* = 6.0, 13.2 Hz, 1H, H-5a/b), 0.008 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ; 137.4, 128.4, 128.3, 127.8, 127.7, 127.6, 109.0, 79.4, 78.7, 73.6, 72.3, 55.3, 53.3, 0.00(3C). ESI-MS; 374 $(M+Na)^+$; Anal. Cal. For $C_{16}H_{25}N_3O_4Si$; C, 54.68; H, 7.17; N, 11.96; Found C, 54.57; H, 7.07; N, 11.85.

6-Azido-5-*O*-methyl-6-deoxy-l,2-*O*-(l-methylethylidene)-3-*O*-trimethylsilyl-α-D-glucofuranose (18a). It was prepared by the general procedure **1** using 0.51 mmol (120 mg) of **18** to yield the desired product **18a** (75%, 127 mg) as a syrapy liquid. IR ($CHCl_3$): 2998, 2106, 1290, 1054, 843cm^{-1}. $[\alpha]^{20}_D$ = -37.8 (c, 1.0, $CHCl_3$). ^1H NMR (400 MHz, $CDCl_3$) δ; 5.86 (d, *J* = 3.6 Hz, 1H), 4.36 (d, *J* =3.6 Hz, 1H), 4.28 (d, *J* =2.4 Hz, 1H), 4.16 (dd, *J* =2.8, 8.8 Hz, 1H), 3.75 (dd, *J* =2.8, 13.6 Hz, 1H), 3.59 (dd, *J* = 4.0, 13.6, 1H, H-6a/b), 3.43 (s, 3H, -OCH_3), 3.39 (dd, *J* = 4.0, 11.6 1H, H-6a/b), 1.56 (s, 3H), 1.33 (s, 3H), 0.19(s, 9H).^{13}C NMR (100 MHz, $CDCl_3$) δ; 111.9, 104.8, 85.1, 79.3, 75.6, 74.0, 57.2, 50.4, 26.7, 26.4, 0.3 (3C). ESI-MS; 354 $(M+Na)^+$; Anal. Cal. For $C_{13}H_{25}N_3O_5Si$; C, 47.11; H, 7.60; N, 12.68; Found C, 46.98; H, 7.49; N, 12.52.

Methyl 6-azido-3,5-di-*O*-benzyl-2-*O*-trimethylsilyl-α-D-glucofuranoside (19a). It was prepared by the general procedure **1** using 0.53 mmol (200 mg) of **19** to yield the desired product **19a** (70%, 176 mg) as syrapy liquid. IR ($CHCl_3$): 3034, 2927.96, 2101.02, 1254.20, 1154.56, 1032.62, 844, 734cm^{-1}. $[\alpha]^{20}_D$ = -28.9 (c, 1.0, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$), δ; 7.32-7.25 (m, 10H), 4.72 (s, 1H), 4.66 (d, *J* =11.2 Hz, 1H), 4.61(d, *J* =11.9 Hz, 1H), 4.53 (s, 1H), 4.49 (d, *J* =11.4 Hz, 1H), 4.35 (dd, *J* =4.4, 8.6 Hz, 1H), 4.16 (s, 1H), 4.04 (m, 1H), 3.87 (d, *J* = 4.6 Hz, 1H), 3.71 (dd, *J* = 2.4, 13.1 Hz, 1H, H-6a/b), 3.43 (dd, *J* = 4.6, 13.1Hz, 1H, H-6a/b), 3.38 (s, 3H, -OCH_3), 0.09 (s, 9H).^{13}C NMR (125 MHz, $CDCl_3$) δ; 138.1, 137.8, 128.5, 128.4, 128.3, 128.2, 128.1, 128.0, 127.9, 127.86, 127.84, 127.7, 110.8, 83.0, 80.4, 78.5, 76.4, 72.4, 72.1, 56.2, 52.1, 0.00 (3C). ESI-MS; 494 $(M+Na)^+$; Anal. Cal. For $C_{24}H_{33}N_3O_5Si$; C, 61.12; H, 7.05; N, 8.91; Found C, 61.02; H, 6.97; N, 8.82.

Methyl 6-azido-3,5-di-*O*-benzyl-2-*O*-trimethylsilyl-α-D-allofuranoside (20a). It was prepared by the general procedure **1** using 0.53 mmol (200 mg) of **20** to yield the desired product **20a** (68%, 171 mg) as a syrapy liquid. IR ($CHCl_3$): 3038, 2956, 2105, 1255, 1157, 1038, 845, 738cm^{-1}. $[\alpha]^{20}_D$ = -68.9 (c, 1.0, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$), δ; 7.32-7.24 (m, 10H), 4.71 (s, 1H), 4.64 (d, *J* =11.2 Hz, 1H), 4.62(d, *J* =11.9 Hz, 1H), 4.55 (s, 1H), 4.52 (d, *J* =11.4 Hz, 1H), 4.37 (dd, *J* = 4.4, 8.6 Hz, 1H), 4.17 (s, 1H), 4.04 (m, 1H), 3.98 (d, *J* = 4.0 Hz, 1H), 3.71 (dd, *J* =2.4, 13.6 Hz, 1H, H-6a/b), 3.43 (dd, *J* = 4.6, 13.6 Hz, 1H, H-6a/b), 3.38 (s, 3H, -OCH_3), 0.09 (s, 9H).^{13}C NMR (125 MHz, $CDCl_3$) δ, 138.1, 137.8, 128.5, 128.4, 128.3, 128.2, 128.1, 128.0, 127.9, 127.86, 127.84, 127.7, 110.8, 83.0, 81.5, 79.0, 76.4, 72.4, 72.1, 56.2, 52.1, 0.00 (3C). ESI-MS; 494 $(M+Na)^+$; Anal. Cal. For $C_{24}H_{33}N_3O_5Si$; C, 61.12; H, 7.05; N, 8.91; Found C, 61.02; H, 6.97; N, 8.82.

6,6'-di-azido-6,6'-di-deoxy-2,3,4,1',3',4'-hexa-*O*-trimethylsilyl sucrose (21b). Prepared by the general procedure **3** using 0.28 mmol (100 mg) of **21** to yield the desired product **21b** (58%, 142 mg) as oily liquid. IR ($CHCl_3$): 2954, 2901, 2110, 1257, 1148, 846, 748cm^{-1} $[\alpha]^{20}_D$ = -58.6 (c, 1.0, $CHCl_3$). ^1H NMR (400 MHz, $CDCl_3$), δ; 5.07 (d, *J* = 4.2 Hz, 1H), 4.16 (d, *J* = 8.0 Hz, 1H), 3.85 (t, *J* = 8.0 Hz, 1H), 3.79-3.73 (m, 1H), 3.71-3.64 (m, 2H), 3.61 (dd, *J* = 8.9 Hz, 17.9 Hz, 1H), 3.52 (dd, *J* = 8.6, 13.0 Hz, 1H), 3.38 (d, *J* =11.1 Hz, 2H), 3.26 (d, *J* = 12.0 Hz, 1H),

3.22-3.19 (m, 2H), 3.05 (dd, J = 3.5, 12.6 Hz 1H), -0.005 (s, 9H), -0.01 (s, 9H), -0.02 (s, 9H), -0.028 (s, 9H), -0.03 (s, 9H), -0.033 (s, 9H). ^{13}C NMR (50 MHz, $CDCl_3$), δ; 103.9, 91.8, 80.4, 76.2, 73.4, 72.9, 72.8, 72.2, 62.8, 53.1, 52.0, 1.1(3C), 1.0 (3C), 0.6 (3C), 0.5 (3C), 0.04 (3C), 0.02 (3C). ESI-MS; 862. $(M+Na)^+$; Anal. Cal. For $C_{31}H_{70}N_6O_9Si_6$; C, 44.36; H, 8.41; N, 10.01; Found C, 44.43; H, 8.36; N, 10.08.

Methyl 3-*O*-benzyl-2,4-di-*O*-trimethylsilyl-α-D-xylopyranoside (22a). It was prepared by the general procedure **1** using 0.59 mmol (150 mg) of **22** to yield the desired product **22a** (80%, 188 mg) as 0ily liquid. IR ($CHCl_3$): 3032, 2969, 1259, 1163, 1056, 849, 742cm^{-1}. $[\alpha]^{20}_D$ = - 39.5 (c, 1.0, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$), δ; 7.37-7.25 (m, 5H), 4.82 (d, J = 11.3 Hz, 1H), 4.78 (d, J = 11.3 Hz, 1H), 4.06 (d, J = 7.5 Hz, 1H), 3.78 (dd, J =5.4, 11.4 Hz, 1H), 3.72-3.68 (m, 1H), 3.49 (s, 3H, -OCH_3), 3.41 (dd, J = 7.6, 8.8 Hz, 1H), 3.29 (dd, J = 8.8, 10.4 Hz, 1H), 3.18 (dd, J = 10.4, 11.2 Hz, 1H), 0.11 (s, 9H), 0.09 (s, 9H). ^{13}C NMR (125 MHz, $CDCl_3$) δ; 138.9, 128.1, 128.0, 127.6, 127.5, 127.2, 105.2, 85.5, 75.4, 70.9, 66.3, 57.0, 0.5 (3C), 0.1 (3C). ESI-MS; 421 $(M+Na)^+$; Anal. Cal. For $C_{19}H_{34}O_5Si_2$; C, 57.25; H, 8.60; Found C, 57.13; H, 8.49.

6-azido-6-deoxy-l,2, 3,4-di--*O*-(l-methyIethyIidene)-α-D-galactopyranoside (23a). It was prepared by the general procedure **1** using 1.0 mmol (260 mg) of **23** to yield the desired product **23a** (67%, 190 mg) as oily liquid. IR ($CHCl_3$): 2987, 2110, 1290, 1054cm^{-1}. $[\alpha]^{20}_D$ = -27.6 (c, 1.0, $CHCl_3$), ^{1}H NMR, (400 MHz, $CDCl_3$) δ; 5.64 (d, J = 4.8 Hz, 1H), 4.73 (dd, J = 2.4, 8.0 Hz, 1H), 4.43 (dd, J = 2.8, 6.4 Hz, 1H), 4.29 (dd, J =2.0, 8.0 Hz, 1H), 4.01 (m, 1H), 3.61 (dd, J =8.0, 12.8 Hz, 1H, H-6a/b), 3.46 (dd, J =5.2, 12.8 Hz, 1H, H-6a/b), 1.67 (s, 3H), 1.56 (s, 3H), 1.41 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ; 110.0, 109.1, 96.7, 71.6, 71.0, 70.8, 61.7, 51.1, 26.4, 26.3, 25.2, 24.8. ESI-MS; 308 $(M+Na)^+$; Anal. Cal. For $C_{12}H_{19}N_3O_5$; C, 50.52; H, 6.71; N, 14.73; Found C, 50.41; H, 6.62; N, 14.61.

3-O-trimethylsilyl-l,2, 5,6-di--*O*-(l-methyIethyIidene)- α-D-glucofuranoside (24a). It was prepared by the general procedure **1** using 0.57 mmol (150 mg) of **24** to yield the desired product **24a** (85%, 162 mg) as oily liquid. IR ($CHCl_3$): 2959, 1256, 1154, 1053, 845, 745cm^{-1}. $[\alpha]^{20}_D$ = - 41.5 (c, 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$), δ; 5.88 (d, J =3.6 Hz, 1H), 4.21 (dd, J =2.4, 8.0 Hz, 1H), 4.18-4.17 (m, 1H), 4.16 (d, J =3.2 Hz, 1H), 4.09- 4.08 (m, 1H), 4.04 (dd, J = 2.8, 8.4 Hz, 1H), 3.96 (dd, J =6.0, 8.4 Hz, 1H), 1.56 (s, 3H), 1.32 (s, 3H), 1.27 (s, 3H), 1.24 (s, 3H), 0.16 (s, 9H). ESI-MS; 355 $(M+Na)^+$; Anal. Cal. For $C_{15}H_{28}O_6Si$; C, 54.19; H, 8.49; Found C, 54.04; H, 8.36.

Methyl 5-amino-5-deoxy-2,3-di-*O*-trimethylsilyl-α-D-ribofuranoside (25). It was prepared by the reported procedure.[19] ^{1}H NMR (200 MHz, $CDCl_3$) δ; 3.91(d, J = 7.4 Hz, 1H), 3.65 (dd, J = 4.9, 10.9 Hz, 1H), 3.09 (d, J = 10.0 Hz, 1H), 3.33 (s, 3H, -OCH_3), 3.09 (d, J = 10.3 Hz, 1H), 3.02 (d, J = 5.6 Hz, 1H), 2.64-2.55 (m, 1H), 0.0008 (s, 18H). ^{13}C NMR (100 MHz, $CDCl_3$) δ; 104.8, 75.0, 71.0, 67.0, 59.6, 56.6, 0.30 (3C), -0.00(3C). ESI-MS; 356 $(M+Na)^+$; Anal. Cal. For $C_{12}H_{27}N_3O_4Si_2$; C, 43.21; H, 8.16; N, 12.60;; Found C, 43.10; H, 8.03; N, 12.43.

Methyl 6-amino-6-deoxy-2,3,4-tri-*O*-trimethylsilyl-α-D-mannopyranoside (26). It was prepared by the reported procedure.[19] ^{1}H NMR (500MHz, $CDCl_3$), δ; 4.36 (bs, 1H), 3.63 (d, J = 1.5 Hz, 1H), 3.60-3.53 (m, 2H), 3.21-3.19 (m, 1H), 3.18 (s, 3H), 2.89-2.87 (m, 1H), 2.65-2.63 (m, 1H), 0.037 (s, 9H), 0.026 (s, 9H), 0.020 (s, 9H). ^{13}C NMR (50 MHz, $CDCl_3$), δ 101.5, 74.7, 73.2, 72.2, 69.8, 54.3, 43.0, 0.75 (3C), 0.59 (3C), 0.46 (3C). ESI-MS; 432 $(M+Na)^+$; Anal. Cal. For $C_{16}H_{39}NO_5Si_3$; C, 46.90; H, 9.59; N, 3.42; Found C, 46.98; H, 9.50; N, 4.51.

Preparation and spectral data for 27. It was prepared by the reported procedure.[20] ^{1}H NMR (400 MHz, $CDCl_3$), δ; 8.20 (s, 1H), 7.42-7.31 (m, 5H), 5.97 (d, J = 3.2 Hz, 1H), 4.87 (dd, J = 2.0, 13.2 Hz, 1H), 4.75 (d, J = 12.0 Hz, 1H), 4.69 (d, J = 3.2 Hz, 1H), 4.59 (d, J = 12.0 Hz, 1H), 4.58-4.51 (m, 2H), 4.47 (dd, J = 2.4, 4.4 Hz, 1H), 4.45 (dd, J = 2.8, 4.0 Hz, 1H), 4.04 (dd, J = 3.2, 5.6 Hz, 1H), 4.01 (d, J = 3.2 Hz, 1H), 1.53 (s, 3H), 1.44 (t, J = 7.2 Hz, 3H), 1.37 (s, 3H), 0.007 (s, 9H).^{13}C NMR (100 MHz, $CDCl_3$) δ, 160.8, 139.8, 137.0, 129.0, 128.8, 128.4, 128.0, 127.9, 127.5, 112.0, 104.9, 82.1, 81.1, 80.0, 72.1, 67.9, 61.1, 54.1, 26.8, 26.7, 14.2, -0.05 (3C). ESI-MS; 528 $(M+Na)^+$; Anal. Cal. For $C_{24}H_{35}N_3O_7Si$; C, 57.01; H, 6.98; N, 8.31; Found C, 56.93; H, 6.85; N, 8.23.

Preparation and spectral data for 28. It was prepared by the reported procedure.[20] ^{1}H NMR (500 MHz, $CDCl_3$), δ 8.35 (s, 1H), 4.81 (d, J = 2.4 Hz, 1H), 4.43 (d, J = 9.6 Hz, 1H), 4.41 (d, J = 2.4 Hz, 1H), 3.97 (s, 3H), 3.82-3.80 (m, 1H), 3.74-3.71 (m, 3H), 3.01 (s, 3H), 0.10 (s, 9H), 0.09 (s, 9H), -0.015 (s, 9H). ^{13}C NMR (50 MHz, $CDCl_3$), δ 161.2, 139.5, 129.2, 101.8, 73.2, 71.3, 71.2, 68.4, 54.7, 51.7, 51.2, 1.2, 1.0, 0.7. ESI-MS; 449 $(M+Na)^+$; Anal. Cal. For $C_{21}H_{43}N_3O_7Si_3$; C, 46.21; H, 7.95; N, 8.08; Found C, 46.11; H, 7.81; N, 7.96.

(3*R*,4*R*,5*R*,6*R*)-Tetrahydroxyazepane (1,6-dideoxy-1,6-imino-D-mannitol) (29). Crude azidosilylated (**12a**) product was obtained following the general procedure (3) using 12 (7.7 mmol, 1.5 gm) followed by the consequent addition of Pd/C (10 mol%) in methnol and 1N HCl (35 mL, 5;1) and hydrogenated (1 atm) for 36h. The mixture was filtered through a layer of celite and washed several times with methanol (20 mL), the filtrate was evaporated under high vacuo. The resulting material was extracted with diethylether and water. The aqueous layer was collected and evaporated under high vaccum. The crude material was recrystallised from methanol-ether (4 mL, 5:1) to obtain the desired product **29** as a white solid in 70% overall yield. The spectral data of **29** was in accordance to the reported one.[22]

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Notes and references

† Electronic Supplementary Information (ESI) available: [Full experimental procedures and copies of ^{1}H and ^{13}C NMR are available]. See DOI: 10.1039/b000000x/

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Graphical abstract:

Azidotrimethylsilylation of carbohydrates (monosaccharides and disaccharides) has been achieved in high yields under Mitsunobu conditions. The azidation of carbohydrates is affected at 0 ^{o}C essentially only at the primary alcoholic position in mono, di- and triols in protected/unprotected glycosides, whereas the remaining secondary hydroxyl groups got silylated. Surprisingly, no azidation was observed in the secondary hydroxyls in all the carbohydrate substrates. Applications of the methodology for the synthesis of aminosugars, triazoles and azasugars are reported.