Note

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Ande Chennaiah, Ashish Kumar Verma, and Yashwant D. Vankar

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TEMPO-Catalyzed Oxidation of 3-*O*-Benzylated/Silylated Glycals to the Corresponding Enones using PIFA-Water Reagent System

Ande Chennaiah, Ashish Kumar Verma and Yashwant D. Vankar*

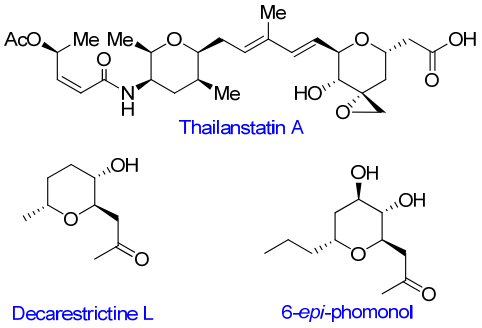
Department of Chemistry, Indian Institute of Technology Kanpur, Kanpur 208016, India

Supporting Information Placeholder

ABSTRACT: A simple, highly efficient and regiospecific method for the direct conversion of 3-*O*-benzylated as well as silylated glycals into the corresponding enones has been developed using PIFA-TEMPO and water reagent system. The reaction is scalable on gram scale under mild conditions with an yield upto 86%.

Hexenuloses or sugar derived 2,3-dihydro-4H-pyran-4-ones are important carbohydrate derivatives which posses a highly reactive α,β-unsaturated-ketone moiety occupying C-1, C-2 and C-3 positions of a sugar molecule.[1a] Since they are excellent Michael acceptors,[1b] these molecules have been widely utilized in the synthesis of a variety of 2-deoxy-*C*- and *O*-glycosides[1,c,d,e] and 2-phosphono-α-*C*-glycosides.[1f] Furthermore, they have been utilized as chiral synthons in the synthesis of complex natural products such as Thailanstatin A,[2a] (+)-Decarestrictine L,[2b] Mycalamides,[2c] 6-*epi*-phomonol[2d] (Figure 1), Diospongin A, ent-Diospongin A and their epimers.[2e] In addition, the keto group can be easily reduced to obtain rare sugars such as D-allal and its derivatives.[2f,g] Therefore, methods for the synthesis of compounds containing a 2,3-dihydro-4H-pyran-4-ones are of great significance.

Figure.1 Examples of some natural products synthesized using hexenuloses as a synthon



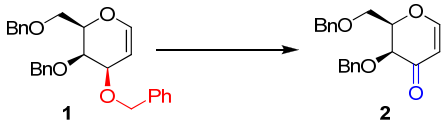
Several methods have been reported for the synthesis of sugar derived 2,3-dihydro-4H-pyran-4-ones, that include traditional allylic oxidation of 3-hydroxy glycals using reagents such as MnO_2,[3a] PDC,[3b] Ag_2CO_3-Celite[3c] and $(Bu_3Sn)_2O$, NIS[3d] etc.[3e-g] In this context, a seminal contribution by Kirschning[4a] and co-workers for the direct oxidation of 3-*O*-protected glycals into the corresponding enones by using hypervalent iodine reagents is noteworthy. The report features the reaction of 3-OAc, 3-OBn, 3-silyl protected glycals with Koser's reagent [PhI(OH)(OTs)][4b] (1.2 equiv) and MS 3 (Å), or alternatively by using (diacetoxyiodo)benzene[4c] (PIDA) (1.2 equiv) along with *p*-TsOH leading to the corresponding enones in moderate to good yields. Furthermore, a modified reagent system comprising of PIDA (2 equiv) and Me_3SiN_3 (4 equiv) in CH_2Cl_2 at −5 °C to room temperature was also reported by Kirschning *et al.*[4d] for the oxidation of 3-*O*-silylated glycals to sugar derived 2,3-dihydro-4H-pyran-4-ones in high yields. However, although these methods are popular, the experimental protocol demands stringent anhydrous conditions (the use of powdered molecular sieves 3 Å being essential). Further, in the case of 3-*O*-Bn protected glycals, the expected C3-oxidized product was obtained in low yields. Thus, development of mild and efficient methods for the synthesis of sugar derived 2,3-dihydro-4H-pyran-4-ones from glycal derivatives is highly desirable.

Recently, we reported[5] a highly regiospecific and stereoselective synthesis of 2-azido-2-deoxysugars from differently protected glycals in one-step by using water-mediated and TEMPO-catalyzed PIFA−Me_3SiN_3 reagent system in the presence of Bu_4NHSO_4 as a phase-transfer catalyst. In our studies, formation of a small amount (~ 5%) of the corresponding 2,3-dihydro-4H-pyran-4-one was observed from C3-OBn and C3-OTBDMS protected glycals during their reaction with PIFA-Me_3SiN_3-TEMPO-H_2O-Bu_4NHSO_4 reagent system in CH_2Cl_2. Intrigued by these results and in continuation of our efforts for the functionalization of glycals,[6] we considered it worth developing reaction conditions that could lead to higher yields of such enones. Herein, we report our findings for an efficient and mild reaction condition for the oxidation of 3-*O*-benzylated (as well as 3-*O*-silylated) glycals to the corresponding 2,3-dihydro-4H-pyran-4-ones using PIFA-water as an oxidizing reagent system along with TEMPO as a catalyst.

As mentioned above, in our recently reported studies[5] (*vide supra*) the reaction of tri-*O*-benzyl-D-galactal **1** with $TMSN_3$ and water in presence of PIFA, TEMPO and Bu_4NHSO_4 resulting in the formation of 2-azido-2-deoxysugar was accompanied by a small amount (~5%) of the corresponding enone. We therefore reasoned that since there was no apparent role of $TMSN_3$ (and perhaps water) in such an oxidation route, excluding these may suppress the formation of 2-azido-2-deoxysugar and permit getting higher yields of the enones. Thus, in our initial studies, reaction of tri-*O*-benzyl-D-galactal **1** with 1.0 equiv of PIFA in CH_2Cl_2 was carried out at 0 °C which led to the corresponding enone **2** in only 6% yield along with the recovered starting material. Increasing the amount of PIFA to 2.0 equiv under same conditions improved the yield of **2** to 28%. However, a significant increase in the yield (78%) of **2** was observed (Table 1, entry 5) when 0.2 equiv of TEMPO was used as a catalyst along with 2.2 equiv of PIFA in CH_2Cl_2 while performing the reaction at 0°C to room temperature in 30 min. Next, we considered checking the effect of water, if any, in this reaction which led to observe that the use of 1.0 equiv of water as an additive under the same conditions was effective and it led to a considerable increase in the

yield of the desired product (86%). Dichloromethane was found to be the ideal solvent in the present work, and the next best solvent was CH_3CN which led to 63% of the enone whereas DMF, THF and toluene failed to give the desired product. It is likely that Lewis basic solvents such as CH_3CN and DMF may deactivate[7] PIFA and thus render them less effective than dichloromethane. Among the hypervalent reagents, PIFA appeared best as other hypervalent iodine reagents such as PIDA and PhIO were found to be unreactive under these conditions. Therefore, the optimized condition was found to be in using 2.2 equiv of PIFA, 0.2 equiv of TEMPO and 1.0 equiv of water at 0 °C to room temperature in 30 min which gave 86% yield of **2** (Table 1, entry 6). Thus, the present method offers a more effective catalyst system for the direct oxidation of tri-*O*-benzyl-D-galactal **1** to corresponding enone **2** as far as yield, time and mild reaction conditions are concerned compared to the methods known in the literature.

Table 1 Optimization of reaction conditions for the formation of enone



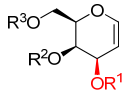
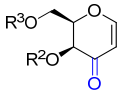
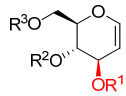
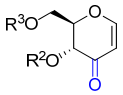
Entry	Oxidant (equiv)	TEMPO (equiv)	H_2O (equiv)	Solvent	Yield(%)
1	PIFA (1)	–	–	CH_2Cl_2	6[a]
2	PIFA (2)	–	–	CH_2Cl_2	28[a]
3	PIFA (2)	0.1	–	CH_2Cl_2	41[a]
4	PIFA (2)	0.1	–	CH_2Cl_2	62[a]
5	PIFA (2.2)	0.2	–	CH_2Cl_2	78
6	**PIFA (2.2)**	**0.2**	**1**	**CH_2Cl_2**	**86**
7	PIFA (2.2)	0.2	1	CH_3CN	63
8	PIFA (2.2)	0.2	1	THF	n.r.
9	PIFA (2.2)	0.2	1	DMF	n.r.
10	PIFA (2.2)	0.2	1	Toluene	n.r.
11	PhIO (2.2)	0.2	1	CH_2Cl_2	n.r.
12	PhIO (2.2)	0.2	1	Toluene	n.r.
13	PhIO (2.2)	0.2	1	CH_3CN	n.r.
14	PIDA (2.2)	0.2	1	CH_2Cl_2	n.r.

Reaction conditions: Glycals (0.720 mmol), $PhI(OCOCF_3)_2$ (1.584 mmol), TEMPO (0.144 mmol), H_2O (0.720 mmol) in CH_2Cl_2 at 0 °C to rt; Isolated yields after purification by silica gel column chromatography; [a] Yield based on recovered starting material

With the established reaction conditions in hand, we tested the reactivity of different glycal derivatives. Thus, galactals and glucals having –OBn group at C-3 (compounds **1**, **3**, **7**, **9**, Table 2) were smoothly converted to the corresponding enones in good to excellent yields. In addition, benzyl-protected D-arabinal **13** (entry 7) and D-xylal **15** (entry 8) also provided the corresponding enone **14** in very good yields. Further, we checked the reactivity of glycals with other protecting groups. Thus, per-*O*-silylated glycals **5** and **11** (entries 3 and 6) under standard reaction conditions gave exclusively the respective enones **6** and **12** in very good yields.

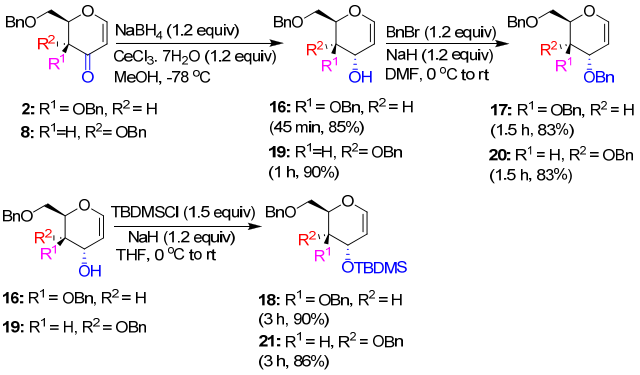
To gain an additional insight as to whether this reagent system can oxidize the –OBn and the –OTBDMS groups occupying different stereochemistry at C-3 position, we prepared a set of compounds. Thus, the D-idal derivatives **17**, **18**, and D-allal derivatives **20**, **21** (Scheme 1) were prepared by performing the Luche reduction[8] of D-galactal and D-glucal derived enones respectively. Thus, compounds **2** and **8** upon reaction with $CeCl_3 \cdot 7H_2O$ and $NaBH_4$ at –78 °C afforded D-idal **16** and D-allal **19** derivatives in 85% and 90% respectively as single diastereomers. Next, protection of the 3-OH group as a TBDMS ether and benzyl ether gave

Table 2 Substrate Scope for the oxidation of Glycals into enones

Entry	Substrate	Product	Time (min)	Yield (%)
				
1	**1:** R^1, R^2, R^3 = **Bn**	**2:** R^2 ,R^3 = **Bn**	30	86
2	**3:** R^1, R^2 = **Bn**, R^3 = **TBDMS**	**4:** R^2 = **Bn**, R^3 = **TBDMS**	35	83
3	**5:** R^1, R^2, R^3 = **TBDMS**	**6:** R^2, R^3 = **TBDMS**	40	78
				
4	**7:** R^1, R^2, R^3 = **Bn**	**8:** R^2, R^3 = **Bn**	50	79
5	**9:** R^1, R^2 = **Bn**, R^3 = **TBDMS**	**10:** R^2 = **Bn**, R^3 = **TBDMS**	45	81
6	**11:** R^1, R^2, R^3 = **TBDMS**	**12:** R^2, R^3 = **TBDMS**	35	76
				
7	**13:** R^1 = **H**; R^2, R^3 = **OBn**	**14:** R^3 = **OBn**	35	82
8	**15:** R^1, R^3 = **OBn**; R^2 = **H**	**14 :** R^3 = **OBn**	25	79

compounds **17**, **18**, **20** and **21** in high yields which were subjected to oxidation by following the procedure developed by us to give the corresponding enones **2** and **8** in good yields (Table 3).

Scheme 1 Synthesis of derivatives of D-allal and D-idal

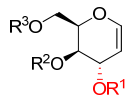
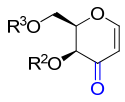
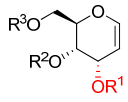
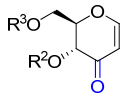
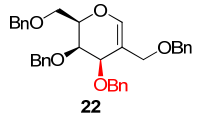
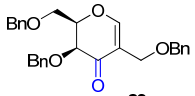
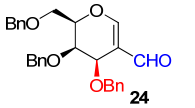


Further, when compound **22**[9] bearing two allylic benzyl ethers, was subjected to oxidation under present conditions, compound **23** was formed as a major product along with **24**[10] as a minor product. We believe that compound **23** could serve as a good synthon in organic chemistry, particularly in carbohydrate chemistry, to synthesize C2-branched sugars.[11] It is noteworthy that under the present reaction conditions, glycals having 3-*O*-acetyl, 3-*O*-benzoyl or 3-*O*-methyl group did not undergo oxidation to the corresponding enones. Further, simple allyl benzyl ether derivatives such as (E)-(2-(benzyloxy)vinyl)benzene (derived from benzyl protected cinammyl alcohol), and (E)-((prop-1-en-1-yloxy)methyl)benzene (derived from benzyl protected crotyl alcohol) were also subjected to our present reaction conditions.[12] Although the former gave the expected cinnamaldehyde, albeit in only 30% yield (as confirmed by GC-MS analysis), it was contaminated with some other inseparable high molecular weight products. On the other hand, with the latter substrate, formation of a

complex mixture was observed. Therefore, it appears most likely that the present method is suitable for sugar derived allyl benzyl ethers, where the double bond is part of an enol ether.

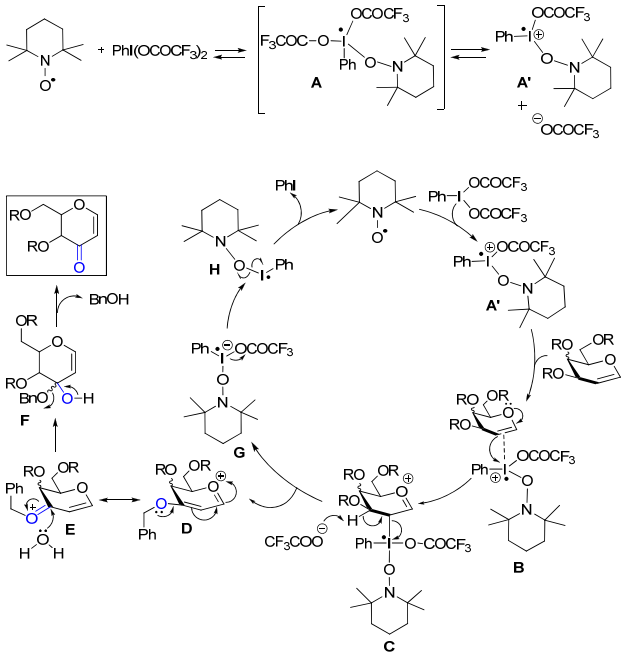
To check the practicality of the current protocol, a gram-scale reaction (upto 5 gm) was performed with tri-*O*-benzyl-D-galactal **1** and tri-*O*-benzyl-D-glucal **7** which afforded the corresponding enones **2** and **8** with no change in the isolated yields.

Table 3. Substrate Scope for the oxidation of Glycals into enones

Entry	Substrate	Product	Time (min)	Yield (%)
				
1	**17:** R^1, R^2, R^3 = **Bn**	**2:** R^2 ,R^3 = **Bn**	30	81
2	**18:** R^1 = **TBDMS**, R^2, R^3 = **Bn**	**2:** R^2 ,R^3 = **Bn**	40	75
				
3	**20:** R^1, R^2, R^3 = **Bn**	**8:** R^2, R^3 = **Bn**	55	80
4	**21:** R^1 = **TBDMS**, R^2, R^3 = **Bn**	**8:** R^2, R^3 = **Bn**	45	82
5	 **22**	 **23** +  **24**	50	62 + 20

A tentative mechanism based on these observations is shown in Scheme 2. We propose that TEMPO may first react with PIFA to form a tetrahedral intermediate A, as has also been proposed

Scheme 2 Tentative mechanism for the conversion of glycals to enones



by Magnus,[13] followed by its decomposition to a trivalent radical cation intermediate A'.[12] The glycal then interacts with A' forming intermediate C, via a π-complex B, which under the reaction conditions may lose a proton from C-3 leading to an oxonium ion D along with the radical anion intermediate G. The resonating oxonium ion E then reacts with water to give the enone via a hemiacetal **F**. In the reaction of benzyl derivatives, the GC-MS analysis of the crude reaction mixture showed the presence of benzyl alcohol indicating that, as shown in Scheme 2, the hemiacetal **F** indeed ejects the benzyloxy group at C-3 to let the oxidation complete. The intermediate **G**,[12] on the other hand, loses trifluroacetate anion forming a radical intermediate **H** which decomposes to iodobenzene and regenerates TEMPO to complete the catalytic cycle.

In conclusion, we have demonstrated a simple one-step protocol for the direct oxidation of 3-*O*-benzyl or 3-*O*-silyl-protected glycals to afford the corresponding enones with PIFA-TEMPO and water reagent system. The reaction generally proceeds in high yields under mild conditions in short time. In addition, this oxidation was found to be independent of the stereochemistry of the –OBn and -OTBDMS groups at C3 of glycals. Moreover, since the reactions are performed in presence of water, exclusion of moisture is not necessary and thus these simple reaction conditions should make the current protocol synthetically useful.

EXPERIMENTAL SECTION

General Information

All experiments were performed in oven-dried apparatus and under a nitrogen atmosphere in dry solvents. Commercial grade solvents were dried by known methods and stored over 4 Å molecular sieves. IR spectra were recorded as a thin film and expressed in cm^{-1}. High resolution mass spectra were recorded by Q-TOF using the electrospray ionization (ESI) method. ^1H (500 MHz or 400 MHz) and ^{13}C (125 MHz or 100 MHz) NMR spectra were recorded using $CDCl_3$ as a solvent. TEMPO and $PhI(OCOCF_3)_2$ were purchased from the Alfa-Aesar Co. and Spectrochem Pvt. Ltd. (Mumbai) respectively. Optical rotations were recorded on an AUTOPOL II polarimeter at 25 °C in CH_2Cl_2. TLC plates were prepared using thin layers of silica gel on microscopic slides, and visualization of spots was done by exposure to iodine or spraying with 10% H_2SO_4 and charring. Column chromatography was performed over silica gel (100−200 Mesh) using hexane and ethyl acetate as eluents.

General procedure for oxidation of C-3 protected glycals to enones 'A'

To a stirred solution of a glycal (500 mg, 1.201 mmol) in CH_2Cl_2 (15 mL) at 0 °C under nitrogen was added $PhI(OCOCF_3)_2$ (1.03 g, 2.643 mmol), TEMPO (38 mg, 0.240 mmol) and water (22 µL, 1.201 mmol). The resulting reaction mixture was slowly brought to room temperature and stirred for appropriate time. Upon completion of the reaction (TLC monitoring), saturated aqueous $NaHCO_3$ solution (5 mL) was added and the mixture extracted with CH_2Cl_2 (2 x 10 mL). The combined organic layers were washed with brine (10 mL) and dried over anhydrous Na_2SO_4. Evaporation of the solvent followed by silica gel column chromatography of the resulting crude residue provided the pure product.

General procedure for reduction enone to enol 'B'

To a solution of sugar enone (1 g, 3.082 mmol) in MeOH (20 mL) at –78 °C was added $CeCl_3 \cdot 7H_2O$ (1.38 g, 3.698 mmol) followed by $NaBH_4$ (1.38 g, 3.698 mmol) in three portions over a period of 15 min. The solution was stirred for the appropriate time at –78

°C, and upon completion of the reaction (TLC monitoring), it was quenched with satd. aqueous NH_4Cl and extracted with ethyl acetate (20 mL x 2). The combined organic layers were washed with water (20 mL), brine (20 mL) and dried over anhydrous Na_2SO_4. Removal of solvent and purification of the crude residue by silica gel column chromatography gave the pure product.

General procedure for benzylation 'C'

To a stirred solution of a 3-hydroxy glycal (500 mg, 1.531 mmol) in dry DMF (10 mL) was added NaH (60% suspension in paraffin oil, 44 mg, 1.839 mmol) followed by benzyl bromide (219 μL, 1.839 mmol) at 0 °C. After the reaction mixture was stirred at room temperature for an appropriate time, (TLC monitoring), it was quenched with ice and the usual workup with ethyl acetate (3 × 10 mL) was followed. The organic phase was washed with brine solution and then dried over anhydrous Na_2SO_4. In vacuo removal of the solvent gave the crude compound which was purified by column chromatography.

General procedure for TBDMS protection 'D'

To a solution of 3-hydroxy glycal (500 mg, 1.531 mmol) in dry THF (10 mL) at 0 °C were added sodium hydride (60% suspension in paraffin oil, 44 mg, 1.839 mmol) and *tert*-butylchlorodimethylsilane (TBDMS-Cl) (346 mg, 2.296 mmol). The reaction mixture was allowed to warm to room temperature and stirred for the required amount of time. Upon complete consumption of starting material (TLC monitoring), the reaction mixture was quenched with water (5 mL) and extracted using ethyl acetate (2 ×10 mL). Combined organic extracts were dried over anhydrous Na_2SO_4 and concentrated in vacuo. The residue was purified by silica gel column chromatography to furnish pure product.

(2R,3S)-3-(benzyloxy)-2-((benzyloxy)methyl)-2H-pyran-4(3H)-one (**2**)**.**
Compound **2** was prepared from **1** (500 mg, 1.201 mmol) using general procedure '**A'** in 86% yield (336 mg) as a colorless oil; R_f = 0.30 (hexane/EtOAc, 8:2); $[\alpha]_D^{28}$ = −23.1 (c 0.7, CH_2Cl_2); IR (neat) ν_{max} /cm^{-1}: 2920,1682; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32 (m, 11H), 5.43 (d, *J* = 6.0 Hz, 1H), 4.71 (d, *J* = 11.9 Hz, 1H), 4.56 (d, *J* = 11.9 Hz, 1H), 4.53 – 4.45 (m, 3H), 3.91 (dd, *J* = 10.2, 7.1 Hz, 1H), 3.74 (dd, *J* = 10.2, 5.3 Hz, 1H), 3.69 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 189.4, 162.7, 137.4, 136.9, 128.49, 128.41, 128.2, 128.0, 127.9, 127.7, 105.1, 80.6, 74.1, 73.6, 71.9, 67.6. HRMS Calcd for $C_{20}H_{21}O_4$ $[M + H]^+$ = 325.1440, found 325.1441.

(2R,3S)-3-(benzyloxy)-2-(((tert-butyldimethylsilyl)oxy) methyl)-2H-pyran-4(3H)-one **(4)**.
Compound **4** was prepared from **3** (500 mg, 1.135 mmol) using general procedure **'A'** in 83% yield (327 mg) as a colorless oil; R_f = 0.60 (hexane/EtOAc, 8:2); $[\alpha]_D^{28}$ = −96.0 (c 0.9, CH_2Cl_2); IR (neat) ν_{max} /cm^{-1}: 2920, 2114, 1679, 831; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38 – 7.26 (m, 7H), 5.43 (dd, *J* = 6.1, 1.6 Hz, 1H), 4.72 (d, *J* = 11.8 Hz, 1H), 4.50 (d, *J* = 11.8 Hz, 1H), 4.36 – 4.31 (m, 1H), 3.97 (dd, *J* = 6.6, 1.5 Hz, 2H), 3.75 (dd, *J* = 2.4, 1.7 Hz, 1H), 0.88 (s, 9H), 0.06 (d, *J* = 1.4 Hz, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.0, 162.8, 137.3, 128.5, 128.2, 128.0, 105.2, 82.2, 74.1, 72.2, 60.5, 25.9, 18.3, -5.30, -5.36; HRMS Calcd for $C_{19}H_{29}O_4Si$ $[M + H]^+$ = 349.1835, found 349.1834.

(2R,3S)-3-((tert-butyldimethylsilyl)oxy)-2-(((tert-butyldimethylsilyl)oxy)methyl)-2H-pyran-4(3H)-one **(6)**.
Compound **6** was prepared from **5** (500 mg, 1.023 mmol) using general procedure **'A'** in 75% yield (298 mg) as a colorless oil; R_f = 0.80 (hexane/EtOAc, 9:1); $[\alpha]_D^{28}$ = −138.0 (c 0.3, CH_2Cl_2); IR (neat) ν_{max} /cm^{-1}: 2929, 1686, 1599, 836; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.29 (d, *J* = 6.0 Hz, 1H), 5.34 (dd, *J* = 6.0, 1.3 Hz, 1H), 4.26 – 4.22 (m, 1H), 4.02 (dd, *J* = 2.6, 1.4 Hz, 1H), 3.93 (d, *J* = 6.4 Hz, 2H), 0.89 (s, 9H), 0.86 (s, 9H), 0.11 (s, 3H), 0.07 (s, 6H), 0.07 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.2, 162.1, 104.9, 83.0, 69.6, 60.3, 25.9, 25.7, 18.3, -4.6, -5.2; HRMS Calcd for $C_{18}H_{37}O_4Si_2$ $[M + H]^+$ = 373.2230, found 373.2233.

(2R,3R)-3-(benzyloxy)-2-((benzyloxy)methyl)-2H-pyran-4(3H)-one **(8)**.
Compound **8** was prepared from 7 (500 mg, 1.201 mmol) using general procedure **'A'** in 79% yield (308 mg) as a colorless oil; R_f = 0.30 (hexane/EtOAc, 8:2); $[\alpha]_D^{28}$ = +67.4 (c 0.6, CH_2Cl_2) ;IR (neat) ν_{max} /cm^{-1}: 2922, 2108, 1682, 1100; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36 – 7.25 (m, 12H), 5.40 – 5.37 (m, 1H), 5.07 (d, *J* = 11.1 Hz, 1H), 4.58 (dd, *J* = 21.9, 10.6 Hz, 3H), 4.43 (dt, *J* = 11.6, 3.3 Hz, 1H), 4.23 (d, *J* = 11.6 Hz, 1H), 3.80 (d, *J* = 3.3 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.6, 162.4, 137.6, 137.5, 128.6, 128.5, 128.4, 128.1, 128.0, 127.9, 105.3, 81.1, 74.7, 74.2, 73.7, 67.9; HRMS Calcd for $C_{20}H_{21}O_4$ $[M + H]^+$ = 325.1440, found 325.1442.

(2R,3R)-3-(benzyloxy)-2-(((tert-butyldimethylsilyl)oxy)methyl)-2H-pyran-4(3H)-one **(10)**.
Compound **10** was prepared from **9** (500 mg, 1.135 mmol) using general procedure '**A**' in 81% yield (319 mg) as a colorless oil; R_f = 0.60 (hexane/EtOAc, 8:2); $[\alpha]_D^{28}$ = −43.5 (c 0.3, CH_2Cl_2); IR (neat) ν_{max} /cm^{-1}: 2928, 2111, 1679, 837; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.38 – 7.27 (m, 7H), 5.44 (dd, *J* = 6.0, 1.6 Hz, 1H), 4.72 (d, *J* = 11.8 Hz, 1H), 4.50 (d, *J* = 11.8 Hz, 1H), 4.34 (ddd, *J* = 6.4, 2.4, 2.0 Hz, 1H), 3.97 (dd, *J* = 6.5, 3.2 Hz, 2H), 3.76 – 3.73 (m, 1H), 0.88 (s, 9H), 0.06 (d, *J* = 1.7 Hz, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.8, 162.4, 137.7, 128.5, 128.3, 128.0, 105.0, 82.5, 74.7, 74.2, 61.5, 25.9, 18.4, -5.1, -5.2; HRMS Calcd for $C_{19}H_{29}O_4Si$ $[M + H]^+$ = 349.1835, found 349.1834.

(2R,3R)-3-((tert-butyldimethylsilyl)oxy)-2-(((tert-butyldimethylsilyl)oxy)methyl)-2H-pyran-4(3H)-one **(12)**.
Compound **12** was prepared from **11** (500 mg, 1.023 mmol) using general procedure **'A'** in 76% yield (286 mg) as a colorless oil; R_f = 0.80 (hexane/EtOAc, 9:1); $[\alpha]_D^{28}$ = −215.0 (c 0.8, CH_2Cl_2); IR (neat) ν_{max} /cm^{-1}: 2925, 1699; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.28 (d, *J* = 5.8 Hz, 1H), 5.31 (d, *J* = 6.1 Hz, 1H), 4.43 (d, *J* = 12.1 Hz, 1H), 4.18 (dt, *J* = 12.2, 2.7 Hz, 1H), 3.99 (d, *J* = 2.7 Hz, 2H), 0.91 (s, 9H), 0.91 (s, 9H), 0.23 (s, 3H), 0.09 (s, 9H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.3, 162.2, 104.9, 83.0, 69.6, 60.3, 25.8, 18.4, -5.2; HRMS Calcd for $C_{18}H_{37}O_4Si_2$ $[M + H]^+$ = 373.2230, found 373.2233.

(R)-3-(benzyloxy)-2H-pyran-4(3H)-one **(14)**.
Compounds **14** was prepared from **13** and **15** (500 mg, 1.687 mmol) using general procedure **'A'** in 82% (281 mg) and 79% (269 mg) respectively, as a colorless oil; R_f = 0.40 (hexane/EtOAc, 8:2); $[\alpha]_D^{28}$ = +84.1 (c 0.5, CH_2Cl_2); IR (neat) ν_{max} /cm^{-1}: 1678, 1597, 1098; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39 – 7.28 (m, 7H), 5.42 (dd, *J* = 6.0, 1.0 Hz, 1H), 4.85 (d, *J* = 11.9 Hz, 1H), 4.62 (d, *J* = 11.9 Hz, 1H), 4.48 (dd, *J* = 12.4, 6.4 Hz, 1H), 4.37 (dd, *J* = 12.4, 4.0 Hz, 1H), 3.83 (ddd, *J* = 6.3, 4.0, 1.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.5, 163.1, 137.3, 128.6, 128.3, 128.2, 105.4, 73.6, 72.6, 71.4; HRMS Calcd for $C_{12}H_{13}O_3$ $[M + H]^+$ = 205.0865, found 205.0862.

(2R,3R,4S)-3-(benzyloxy)-2-(benzyloxymethyl)-3,4-dihydro-2H-pyran-4-ol **(16)**.
Compound **16** was prepared from **2** (400 mg, 1.233 mmol) using general procedure **'B'** in 85% yield (342 mg) as a colorless oil; R_f = 0.30 (hexane/EtOAc, 8:2); $[\alpha]_D^{28}$ = −18.2 (c 0.2, CH_2Cl_2); IR (neat) ν_{max} /cm^{-1}: 3100, 1648, 921; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 – 7.24 (m, 10H), 6.36 (d, *J* = 6.1 Hz, 1H), 4.77 – 4.72 (m, 1H), 4.68 (t, *J* = 10.1 Hz, 2H), 4.57 (d, *J* = 11.9 Hz, 1H), 4.48 (d, *J* = 11.9 Hz, 1H), 4.33 (dd, *J* = 6.5, 2.7 Hz, 1H), 4.18 (td, *J* = 6.5, 2.3 Hz, 1H), 3.92 – 3.87 (m, 1H), 3.79 (dd, *J* = 10.0, 6.6 Hz, 1H), 3.63 (dd, *J* = 10.1, 5.6 Hz, 1H), 2.36 (t, *J* = 9.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 144.3, 137.8, 128.7, 128.5, 128.2, 127.9, 103.0, 75.2, 74.3, 73.6, 73.2, 68.2, 62.9; HRMS Calcd for $C_{20}H_{23}O_4$ $[M + H]^+$ = 327.1596, found 327.1593.

(2R,3R,4S)-3,4-bis(benzyloxy)-2-(benzyloxymethyl)-3,4-dihydro-2H-pyran **(17)**.
Compound **17** was prepared from **16** (300 mg, 0.919 mmol) using general procedure **'C'** in 83% yield (318 mg) as a colorless oil; R_f = 0.70 (hexane/EtOAc, 8:2); $[\alpha]_D^{28}$ = +62.4 (c 0.7, CH_2Cl_2); IR (neat) ν_{max} /cm^{-1}: 2963, 1656, 735; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37 – 7.22 (m, 15H), 6.36 (dd, *J* = 6.2, 1.4 Hz, 1H), 4.89 – 4.83 (m, 2H), 4.67 – 4.59 (m, 3H), 4.45 (dd, *J* = 32.4, 11.9 Hz, 2H), 4.17 (dd, *J* = 3.6, 2.5 Hz, 2H), 3.95 – 3.92 (m, 1H), 3.78 (dd, *J* = 10.1, 7.2 Hz, 1H), 3.64 (dd, *J* = 10.1, 5.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 144.2, 138.5, 138.4, 138.0, 128.48, 128.42, 128.2, 128.0, 127.7, 127.6, 127.5, 100.0, 75.7, 73.5, 73.4, 71.3, 70.9, 70.8, 68.5; HRMS Calcd for $C_{27}H_{28}NaO_4$ $[M + Na]^+$ = 439.1885, found 439.1881.

((2R,3S,4S)-3-(benzyloxy)-2-(benzyloxymethyl)-3,4-dihydro-2H-pyran-4-yloxy)(tert-butyl)dimethylsilane **(18)**.
Compound **18** was prepared from **16** (300 mg, 0.919 mmol) using general procedure **'C'** in 83% yield (365 mg) as a colorless oil; R_f = 0.70 (hexane/EtOAc, 8:1); $[\alpha]_D^{28}$ = +41.8 (c 0.9, CH_2Cl_2); IR (neat) ν_{max} /cm^{-1}: 2941, 1660, 738; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37 – 7.24 (m, 10H), 6.30 (dd, *J* = 6.2, 1.4 Hz, 1H), 4.90 (d, *J* = 11.9 Hz, 1H), 4.67 (ddd, *J* = 6.2, 3.1, 1.1 Hz, 1H), 4.58 (d, *J* = 11.9 Hz, 1H), 4.44 (q, *J* = 12.0 Hz, 3H), 4.19 (s, 1H), 3.78 – 3.71 (m, 2H), 3.57 (dd, *J* = 10.3, 4.7 Hz, 1H), 0.90 (s, 9H), 0.09 (d, *J* = 2.1 Hz, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 143.3, 138.6, 138.1, 128.5, 128.4, 128.1, 128.0, 127.8, 127.7, 103.3, 75.8, 73.5, 73.2, 68.6, 25.9, 18.2, -4.3, -4.6; HRMS Calcd for $C_{26}H_{37}O_4Si$ $[M + H]^+$ = 441.2461, found 441.2459.

(2R,3R,4S)-3-(benzyloxy)-2-(benzyloxymethyl)-3,4-dihydro-2H-pyran-4-ol **(19)**.
Compound **19** was prepared from **8** (200 mg, 0.616 mmol) using general procedure **'B'** in 90% yield (181 mg) as a colorless oil; R_f = 0.30 (hexane/EtOAc, 8:2); $[\alpha]_D^{28}$ = −56.4 (c 0.6, CH_2Cl_2); IR (neat) ν_{max} /cm^{-1}: 3100, 1661, 917; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40 – 7.23 (m, 11H), 6.38 (dd, *J* = 6.0, 1.4 Hz, 1H), 4.78 (d, *J* = 11.6 Hz, 1H), 4.74 – 4.68 (m, 1H), 4.68 – 4.64 (m, 1H), 4.62 (d, *J* = 1.7 Hz, 1H), 4.57 (dd, *J* = 12.0, 1.7 Hz, 1H), 4.32 (s, 1H), 3.97 (dd, *J* = 6.4, 2.7 Hz, 1H), 3.82 – 3.78 (m, 2H), 3.67 (ddd, *J* = 9.6, 3.1, 1.5 Hz, 1H), 2.02 (d, *J* = 5.1 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 144.5, 138.2, 137.7, 128.5, 128.4, 127.9, 127.8, 127.7, 102.7, 76.7, 73.7, 73.6, 69.0, 68.7; HRMS Calcd for $C_{20}H_{23}O_4$ $[M + H]^+$ = 327.1596, found 327.1593.

(2R,3S,4S)-3,4-bis(benzyloxy)-2-(benzyloxymethyl)-3,4-dihydro-2H-pyran **(20)**.
Compound **20** was prepared from **19** (300 mg, 0.919 mmol) using general procedure 'C' in 83% yield (318 mg) as a colorless oil; R_f = 0.70 (hexane/EtOAc, 8:2); $[\alpha]_D^{28}$ = +38.6 (c 0.4, CH_2Cl_2); IR (neat) ν_{max} /cm^{-1}: 2951, 1642, 731; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.34 – 7.19 (m, 15H), 6.42 (dd, *J* = 6.1, 0.9 Hz, 1H), 4.89 – 4.81 (m, 2H), 4.65 (d, *J* = 2.9 Hz, 1H), 4.61 (t, *J* = 3.6 Hz, 1H), 4.55 (t, *J* = 8.8 Hz, 3H), 4.21 (dd, *J* = 6.1, 2.1 Hz, 1H), 4.06 (ddd, *J* = 8.2, 4.9, 2.9 Hz, 1H), 3.89 – 3.73 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 144.8, 138.4, 138.2, 138.0, 128.4, 128.0, 127.89, 127.83, 127.7, 100.0, 75.8, 74.4, 73.8, 73.5, 70.5, 68.6; HRMS Calcd for $C_{27}H_{29}O_4$ $[M + H]^+$ = 417.2066, found 417.2061.

((2R,3R,4S)-3-(benzyloxy)-2-(benzyloxymethyl)-3,4-dihydro-2H-pyran-4-yloxy)(tert-butyl)dimethylsilane **(21)**.
Compound **21** was prepared from **19** (300 mg, 0.919 mmol) using general procedure **'C'** in 86% yield (378 mg) as a colorless oil; R_f = 0.70 (hexane/EtOAc, 8:1); $[\alpha]_D^{28}$ = +14.1 (c 0.2, CH_2Cl_2); IR (neat) ν_{max} /cm^{-1}: 2967, 1651, 752; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35 – 7.25 (m, 11H), 6.34 (dd, *J* = 6.1, 1.1 Hz, 1H), 4.82 (d, *J* = 11.3 Hz, 1H), 4.67 – 4.61 (m, 2H), 4.56 (s, 2H), 4.36 – 4.33 (m, 1H), 4.08 – 4.04 (m, 1H), 3.78 (dd, *J* = 10.8, 5.5 Hz, 1H), 3.68 (ddd, *J* = 14.4, 9.6, 4.3 Hz, 2H), 0.90 (s, 9H), 0.08 (d, *J* = 4.8 Hz, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 143.5, 138.1, 128.54, 128.51, 128.0, 127.9, 127.7, 103.6, 74.1, 73.6, 69.1, 68.8, 25.9, 18.1, 0.1, -4.2, -4.5; HRMS Calcd for $C_{26}H_{37}O_4Si$ $[M + H]^+$ = 441.2461, found 441.2459.

(2R,3S)-3-(benzyloxy)-2,5-bis(benzyloxymethyl)-2H-pyran-4(3H)-one **(23)**.
To a well stirred solution of **22** (200 mg, 0.372 mmol) in CH_2Cl_2 (7 mL) was added $PhI(OCOCF_3)_2$ (353 mg, 0.819 mmol), TEMPO (12 mg, 0.074 mmol) and water (7 μL, 0.372 mmol). The resulting reaction mixture was slowly brought to room temperature and stirred until completion of the reaction (TLC monitoring). The reaction mixture was treated with satd. aq. $NaHCO_3$ solution (5 mL) and extracted with CH_2Cl_2 (2 x 10 mL). The combined organic layers were washed with brine (10 mL) and dried over anhydrous Na_2SO_4. Evaporation of the solvent followed by silica gel column chromatography of the resulting crude residue provided **23** in 62% (103 mg) and **24** in 20% (33 mg) as a colorless oil. Data for **23**: R_f = 0.50 (hexane/EtOAc, 7:3); $[\alpha]_D^{28}$ = +69.7 (c 0.18, CH_2Cl_2); IR (neat) ν_{max} /cm^{-1}: 2976, 1653, 763; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.48 (s, 1H), 7.35 – 7.22 (m, 15H), 4.70 (d, *J* = 11.9 Hz, 1H), 4.58 – 4.51 (m, 3H), 4.52 – 4.46 (m, 3H), 4.17 (dd, *J* = 31.2, 11.8 Hz, 2H), 3.90 (dd, *J* = 10.2, 6.9 Hz, 1H), 3.76 (dd, *J* = 10.2, 5.5 Hz, 1H), 3.73 (d, *J* = 2.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 188.7, 162.1, 138.2, 137.6, 137.1, 128.59, 128.50, 128.3, 128.1, 128.0, 127.88, 127.84, 127.7, 113.7, 80.7, 73.9, 73.7, 72.5, 72.1, 67.6, 63.8; HRMS Calcd for $C_{28}H_{28}NaO_5$ $[M + H]^+$ = 467.1834, found 467.1831.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website.

AUTHOR INFORMATION

Corresponding Author

*E-mail: vankar@iitk.ac.in.

Notes

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REFERENCES

(1) (a) Holder, N. L. The Chemistry of Hexenuloses. *Chem. Rev*. **1982**, *82*, 287–332. (b) Michael, K.; Kessler, H. MICHAEL-Type Additions in the Synthesis of α-O- and -S-2-Deoxyglycosides. *Tetrahedron Lett*. **1996**, 37, 3453–3456. (c) Ramnaulth, J.; Poulin, O.; Bratovanov, S. S.; Rakhit, S.; Maddaford, S. P. Stereoselective *C*-Glycoside Formation by a Rhodium(I)-Catalyzed 1,4-Addition of Arylboronic Acids to Acetylated Enones Derived from Glycals. *Org. Lett*. **2001**, *3*, 2571–2573. (d) Goodwin, T. E.; Rothman, N. M.; Salazar, K. L.; Sorrels, S. L.; Evans, F. E. Stereoselectivity Reversals in Conjugate Additions to a 2,3-Dihydro-4H-pyran-4-one. *J. Org. Chem*. **1992**, 57, 2469–2471. (e) Lin, H.-C.; Wu, H.-H.; Lin, Z.-P.; Lin, C.-Y.; Lin, C.-H.; Chen, K.-L.; Wong, F. F. Microwave-assisted stereoselective α-2-deoxyglycosylation of hex-1-en-3-uloses. *Tetrahedron Lett*. **2009**, *50*, 7327–7329. (f) Leonelli, F.; Capuzzi, M.; Calcagno, V.; Passacantilli, P.; Piancatelli, G. Stereoselective Michael-Type Addition of Organocopper Reagents to Enones Derived from Glycals in the Synthesis of 2-Phosphono-α-C-Glycosides. *Eur. J. Org. Chem*. **2005**, 2671–2676.

(2) (a) Nicolaou, K. C.; Rhoades, D.; Lamani, M.; Pattanayak, M. R.; Kumar, S. M. Total Synthesis of Thailanstatin A. *J. Am. Chem. Soc*. **2016**, *138*, 7532–7535. (b) Zuniga, A.; Perez, M.; Pazos, G.; Gomez, G.; Fall, Y. A Concise, Enantioselective Synthesis of (+)-Decarestrictine L from Tri-O-acetyl-D-glucal. *Synthesis* **2010**, 2446−2450. (c) Gardiner, J. M.; Mills, R.; Fessard, T. Synthesis of model ring systems related to C10–C18 analogues of the mycalamides/theopederins. *Tetrahedron Lett*. **2004**, *45*, 1215−1217. (d) Garrido, F.; Santalla, H.; Gómez, G.; Fall, Y. First total synthesis of 6-epi-phomonol. *Tetrahedron Lett*. **2016**, *57*, 2631−2632. (e) Zúñiga, A.; Pérez, M.; Gándara, Z.; Fall, A.; Gómez, G.; Fall, Y. Synthesis of diospongin A, ent-diospongin A and C-5 epimer of diospongin B from tri-O-acetyl-D-glucal. *Arkivoc* **2015**, *7*, 195–215. (f) Fujiwara, T.; Hayashi, M. Efficient Synthesis of Rare Sugar D-Allal via Reversal of Diastereoselection in the Reduction of Protected 1,5-Anhydrohex-1-en-3-uloses: Protecting Group Dependence of the Stereoselection. *J. Org. Chem*. **2008**, *73*, 9161–9163. (g) Sakakibara, T.; Tsubasa, T.; Kotaka, C.; Kajihara, Y.; Watanabe, Y.; Fujioka, A. A facile synthesis of 4,6-O-benzylidene-D-glycals via 1,5-anhydro-4,6-O-benzylidene-D-hex-1-en-3-ulose. *Carbohydr. Res.* **2008**, *343*, 2740–2743.

(3) (a) Fraser-Reid, B.; McLean, A.; Usherwood, E. W.; Tunker, M. Pyranosiduloses. II. The synthesis and properties of some alkyl 2,3-dideoxy-2-enopyranosid-4-uloses. *Can. J. Chem.* **1970**, *48*, 2877–2884. (b) Czernecki, S.; Vijayakumaran, K.; Ville, G. Convenient Synthesis of Hex-1-enopyran-3-uloses: Selective Oxidation of Allylic Alcohols Using Pyridinium Dichromatete. *J. Org. Chem*. **1986**, *51*, 5472–5475. (c) Tronchet, J. M. J.; Tronchet, J.; Birkhauser, A. Oxydation allylique selective en chimie des sucres au moyen du reactif de Fetizon. *Helv. Chim. Acta*. **1970**, *53*, 1489–1490. (d) Czernecki, S.; Leteux, C.; Veyrieres, A. Versatile Behavior of *O*-Stannylated D-Glucal Towards Halogens. *Tetrahedron Lett*. **1992**, *33*, 221–224. (e) Bellosta, V.; Benhaddou, R.; Czernecki, S. Selective Homogeneous Oxidation of Allylic Alcohols with Palladium (II) Salts. *Synlett* **1993**, 861–863. (f) Hayashi, V.M.; Yamada, K.; Nakayama, S. Dehydrogenation of D-Glycals by Palladium Supported on Activated Charcoal under Ethylene Atmosphere: Synthesis of 1,5-Anhydrohex-1-en-3-uloses. *Synthesis* **1999**, 1869–1871. (g) Bouillot, A.; Do Khac, D.; Fetizon, M.; Guir, F.; Memoria. Y. Convenient Preparations of 2,3- Dihydro-4H-pyran-4-ones from D-Glucal Triacetate: Selective Oxidations of Alyllic Acetates and Allylic Silyl Ethers Using N-Bromosuccinimide. *Synth. Commun*. **1993**, *23*, 2071–2081.

(4) (a) Kirschning, A. Hypervalent Iodine and Carbohydrates – A New Liaison. *Eur. J. Org. Chem*. **1998**, 2267–2274. (b) Kirschning, A.; Dräger, G.; Harders, J. Regioselective Oxidation of Glycals with Hypervalent Iodine Reagents. *Synlett* **1993**, 289–290. (c) Kirschning, A. Oxidation of Fully Protected Glycals by Hypervalent Iodine Reagents. *J. Org. Chem.***1995**, *60*, 1228–1232. (d) Kirschning, A.; Hary, U.; Plumeier, C.; Ries, M.; Rose, L. Simple oxidation of 3-*O*-silylated glycals: application in deblocking 3-*O*-protected glycals. *J. Chem. Soc. Perkin Trans 1*. **1999**, 519–528. (e) Kirschning, A.; Bechthold, A.; Rohr, J. Chemical and biochemical aspects of deoxysugars and deoxysugar oligosaccharides. *Top. Curr. Chem.* **1997**, *188*, 1–84.

(5) Chennaiah, A.; Vankar, Y. D. One-Step TEMPO-Catalyzed and Water-Mediated Stereoselective Conversion of Glycals into 2-Azido-2-deoxysugars with a PIFA–Trimethylsilyl Azide Reagent System. *Org. Lett*. **2018**, *20*, 2611−2614.

(6) (a) Dharuman, S.; Vankar, Y. D. N-Halosuccinimide/AgNO3: Efficient reagent systems for one step synthesis of 2-halo glycals from glycals: Application in the synthesis of 2C-branched sugars via Heck coupling reactions. *Org. Lett*. **2014**, *16*, 1172−1175. (b) Reddy, B. G.; Madhusudanan, K. P.; Vankar, Y. D. Trimethylsilylnitrate-Trimethylsilylazide: A Novel Reagent System for the Synthesis of 2-Deoxy Glycosyl Azides from Glycals: Application in the Synthesis of 2-Deoxy-β-*N*-glycopeptides. *J. Org. Chem.* **2004**, *69*, 2630−2633. (c) Rawal, G. K.; Kumar, A.; Tawar, U.; Vankar, Y. D. New method for chloroamidation of olefins. Application in the synthesis of *N*-glycopeptides and anticancer agents. *Org. Lett*. **2007**, *9*, 5171−5174. (d) Reddy, B. G.; Vankar, Y. D. Synthesis of novel hybrids of D-galactose with 1-deoxynojirimycin analogues as glycosidase inhibitors. *Angew. Chem., Int. Ed.* **2005**, *44*, 2001−2004. (e) Chennaiah, A.; Bhowmick, S.; Vankar, Y. D. Conversion of glycals into vicinal-1,2-diazides and 1,2-(or 2,1)-azidoacetates using hypervalent iodine reagents and Me_3SiN_3. Application in the synthesis of *N*-glycopeptides, pseudo-trisaccharides and an iminosugar. *RSC Adv*. **2017**, *7*, 41755−41762.

(7) Gieuw, M. H.; Ke, Z.; Yeung, Y.-Y. Lewis Base-Promoted Ring-Opening 1,3-Dioxygenation of Unactivated Cyclopropanes Using a Hypervalent Iodine Reagent. *Angew. Chem., Int. Ed.*, **2018**, *57*, 3782–3786. We thank the referee to suggest this reference.

(8) Luche, J. –L.; Gemal, A. L. Lanthanoids in Organic Synthesis. 5. Selective Reductions of Ketones in the Presence of Aldehydes. *J. Am. Chem. Soc.* **1979**, *101*, 5848–5849. (b) Sridhar, P. R.; Venukumar, P. A Ring Expansion-Glycosylation Strategy toward the Synthesis of Septano-oligosaccharides. *Org. Lett.* **2012**, *14*, 5558−5561.

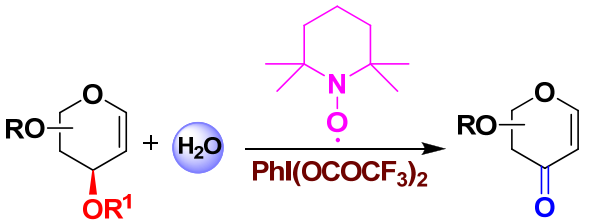
(9) Nagaraj, P.; Ramesh, N. G. InCl3-Catalyzed Rapid 1,3-Alkoxy Migration in Glycal Ethers: Stereoselective Synthesis of Unsaturated α-O-Glycosides and an α,α-(1→1)-Linked Disaccharide. *Eur. J. Org. Chem.* **2008**, 4607–4614.

(10) Ramesh, N. G.; Balasubramanian, K. K. Vilsmeier-Haack Reaction of Glycals A Short Route To C-2-Formyl Glycals. *Tetrahedron Lett*. **1991**, *32*, 3875−3878.

(11) Vankar Y. D.; Linker T. Recent Developments in the Synthesis of 2-*C*-Branched and 1,2-Annulated Carbohydrates *Eur. J. Org. Chem.* **2015**, 7633−7642.

(12) We thank one of the referees to suggest the possible intermediacy of **A'** prior to its reaction with glycal. We also thank the same referee for suggesting to include the intermediates **G** and **H** in the mechanism. Also, thanks are accorded to this referee for asking us to conduct these experiments.

(13) (a) Magnus, P.; Lacour, J. New Trialkylsilyl Enol Ether Chemistry. Conjugate Additions without the Enone. *J. Am. Chem. Soc.* **1992**, *114*, 3993−3994. (b) Magnus, P.; Lacour, J.; Evans, P. A.; Roe, M. B.; Hulme, C. Hypervalent Iodine Chemistry: New Oxidation Reactions Using the Iodosylbenzene-Trimethylsilyl Azide Reagent Combination. Direct α- and β-Azido Functionalization of Triisopropylsilyl Enol Ethers. *J. Am. Chem. Soc.* **1996**, *118*, 3406−3418. (c) Magnus, P.; Roe, M. B.; Hulme, C. New Trialkylsilyl Enol Ether Chemistry: Direct 1,2-Bis-azidonation of Triisopropylsilyl Enol Ethers: an Azido-radical Addition Process Promoted by TEMPO. *J. Chem. Soc., Chem. Commun*. **1995**, 263−265.



R^1 = Bn or TBS

- Upto 86% yield
- Gram scale
- Mild conditions
- Metal free
- Water as an additive