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Studies on epoxidation of enantiomerically pure 2,3-dideoxy hex-2-enitols: a convenient access to highly functionalized enantiomerically pure tetrahydrofuran derivatives☆

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Abstract—A detailed comparative study on the epoxidation of enantiomerically pure allylic alcohols **8**–**14** derived from their respective glycals with Sharpless, *m*-CPBA and Camp's reagents was carried out in order to obtain 2,3-epoxy alcohols keeping in view the versatility of these synthons in synthetic chemistry for the preparation of various molecules of biological importance by suitable chemical transformations. During the course of this study, the Sharpless asymmetric epoxidation reaction was found to be an unprecedented alternative, due to its mild reaction conditions, for synthesizing highly functionalized enantiomerically pure tetrahydrofuran derivatives. A detailed mechanistic pathway of their formation has also been studied.

1. Introduction

The total synthesis of functionally and stereochemically complex naturally occurring bioactive compounds, using highly functionalized acyclic monosaccharide derivatives as chiral synthons, has become almost routine for many years.[1,2] These chiral building blocks are available in various forms and can be obtained from cyclic sugar derivatives by suitable chemical transformations. One of the most proven versatile acyclic monosaccharide chiral starting materials is glycal derived unsaturated deoxy sugar aldehydes, which we call Perlin aldehydes of the general structure **I**.[3] These molecules have been exploited for the synthesis of various types of biologically active compounds.[4] Over the last few years we have been using these molecules as precursors for the synthesis of terminal amino alcohols as anti-tubercular agents.[5,6] Recently we have also shown that **I**, with acyl protection of its hydroxyls, underwent almost completely diastereoselective annulations with 4-hydroxy pyrone derivatives in the presence of L-proline to generate pyrano pyrons.[7]

Thus, considering **I** as a versatile synthetic building block, we are further interested to make the best use of **I** to generate 2,3-epoxy alcohols **III**, the precursors for obtaining secondary amino alcohols by introducing an amino group regio- and stereoselectively at either of the two deoxy unsaturated carbons C-2 or C-3. The 2,3-epoxy alcohol **III** could be derived from enantiomerically pure allylic alcohol **II** by epoxidation. Very recently the allylic alcohols of type **II** have been used for the synthesis of polyhydroxylated surfactants.[8] A thorough literature survey on **III** revealed that its synthesis has not yet been reported from **II** (Fig. 1). However, the synthesis of 2,3-epoxy alcohols of type **III** has been reported by Sharpless et al.[9] In this communication, they reported the synthesis of **IIIA** from tetrose **IIA** to make various hexitols. The same group has also reported in their next article,[10] the usage of 2,3-epoxy alcohols derived from tetrose **IIA** towards the synthesis of saccharides and related polyhydroxylated natural products. The 2,3-epoxy alcohols of type **III** have recently been shown by Somfai and Lindström to be an important synthon for the asymmetric synthesis of 1-deoxynojirimycin (DNJ).[11]

Thus the synthetic importance of 2,3-epoxy alcohol **III** prompted us to develop an alternative method for its synthesis, on a preparative scale, starting from easily available Perlin aldehyde **I**. Recently, we have shown the application of 2,3-epoxy alcohols of type **III** for the synthesis of

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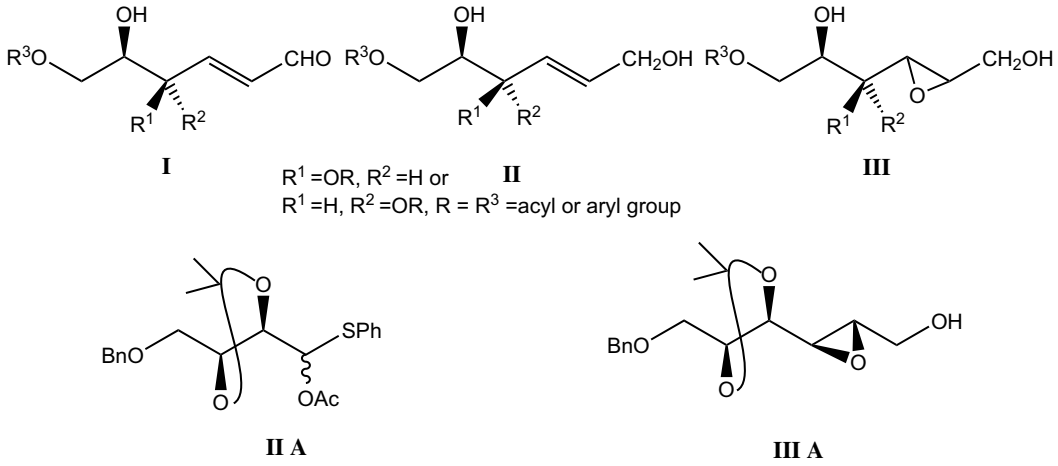


Figure 1.

polyhydroxylated terminal alkenic alcohols.[12] Herein we report the results of a detailed comparative study on epoxidation of **II** by Sharpless,[13,14] *m*-CPBA and *m*-CPBA/KF (Camp's reagent)[15] reagents.

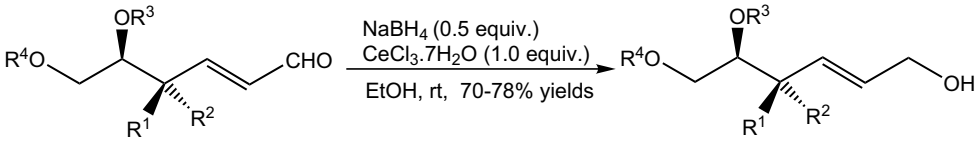
2. Results and discussion

The starting materials required for the present study were prepared by reduction of the appropriate Perlin aldehydes **1**–**7** by adapting the procedure developed by Luche[16] (Scheme 1).

With the required substrates in hand, the stage was set to carry out a detailed study on epoxidation of allylic alcohols by the Sharpless asymmetric reaction. For this, compound **8** was submitted to Sharpless asymmetric epoxidation (SAE) with *t*-BuOOH (3.0 equiv 6.0 M solution in nonane) in the presence of Ti(O–*i*-Pr)$_4$ (2.0 equiv) and L-(+)-DET (2.5 equiv) in DCM. After exploring several trial experiments at various low temperatures below 0 °C, it was found that initiating the reaction at −25 °C and continuing it to 0 °C for 10 h, showed almost complete diastereoselectivity (>99%) furnishing the epoxy derivative **8a** [(2*S*,3*R*)-4,6-di-*O*-benzyl-2,3-epoxy-D-galactitol] in 70% yield (Scheme 2).

At this stage, we became interested in the order of selectivity in Sharpless asymmetric epoxidation of the allylic alcohol with other tartrate, as well as the results of the catalytic version of SAE.[17] Therefore, the first SAE of **8** was carried out using D-(−)-DIPT (2.5 equiv). Here also, the reaction proceeded with complete diastereoselectivity (>99%), furnishing the highly functionalized epoxy derivative [(2*R*,3*S*)-4,6-di-*O*-benzyl-2,3-epoxy-D-galactitol] **8b** in 60% yield after 10h of continuous stirring of the reaction mixture (Scheme 3). In the study of a catalytic version of SAE on the allylic alcohol **8**, the use of 2.4 equiv of *t*-BuOOH, 0.05 equiv of Ti(O–*i*-Pr)$_4$ and 0.06 equiv of L-(+)-DET did not show any results. However when the amounts of Ti(O–*i*-Pr)$_4$ and L-(+)-DET were increased to 0.10 and 0.12 equiv, respectively, keeping the amount of *t*-BuOOH constant, it was noticed that the reaction took place smoothly with the same selectivity but requiring more time for completion (25 h, Table 1, entry 2). On further increase of the amounts of Ti(O–*i*-Pr)$_4$ and L-(+)-DET to 0.20 and 0.24 equiv, respectively, SAE occurred exactly at the same rate, with the same selectivity and yield as was noticed in the case when 2.0 equiv of Ti(O–*i*-Pr)$_4$ and 2.5 equiv of L-(+)-DET were used for the SAE of **8**.

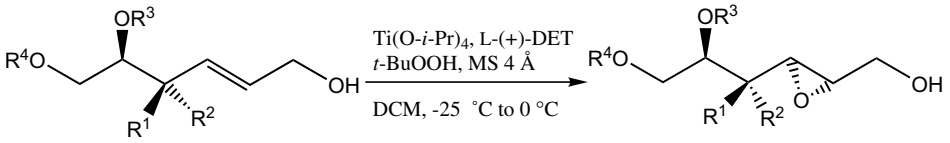
Thus, based on the selectivity observed in the SAE of **8** in the temperature range −25 °C to 0 °C, and considering the



1. R^1=OBn, R^2=R^3=H, R^4=Bn
2. R^1=R^3=H, R^2=OBn, R^4=Bn
3. R^1=OBn, R^2=H, R^3=R^4=Bn
4. R^1=H, R^2=OBn, R^3=R^4=Bn
5. R^1=OBn, R^2=H, R^3=Ac, R^4=Bn
6. R^1=OAc, R^2=H, R^3=R^4=Ac
7. R^1=H, R^2=OAc, R^3=R^4=Ac

8. R^1=OBn, R^2=R^3=H, R^4=Bn
9. R^1=R^3=H, R^2=OBn, R^4=Bn
10. R^1=OBn, R^2=H, R^3=R^4=Bn
11. R^1=H, R^2=OBn, R^3=R^4=Bn
12. R^1=OBn, R^2=H, R^3=Ac, R^4=Bn
13. R^1=OAc, R^2=H, R^3=R^4=Ac
14. R^1=H, R^2=OAc, R^3=R^4=Ac

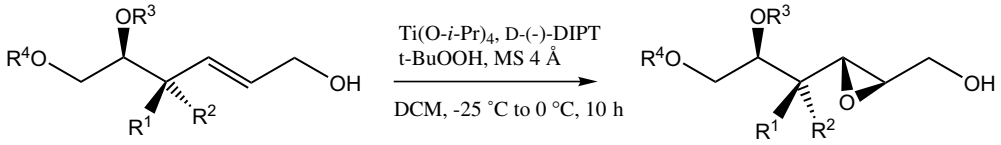
Scheme 1. Reduction of α,β-unsaturated enals to allylic alcohols.



8. R^1=OBn, R^2=R^3=H, R^4=Bn
9. R^1=R^3=H, R^2=OBn, R^4=Bn
10. R^1=OBn, R^2=H, R^3=R^4=Bn
11. R^1=H, R^2=OBn, R^3=R^4=Bn
12. R^1=OBn, R^2=H, R^3=Ac, R^4=Bn
13. R^1=OAc, R^2=H, R^3=R^4=Ac
14. R^1=H, R^2=OAc, R^3=R^4=Ac

8a. R^1=OBn, R^2=R^3=H, R^4=Bn
9a. R^1=R^3=H, R^2=OBn, R^4=Bn
10a. R^1=OBn, R^2=H, R^3=R^4=Bn
11a. R^1=H, R^2=OBn, R^3=R^4=Bn
12a. R^1=OBn, R^2=H, R^3=Ac, R^4=Bn
13a. R^1=OAc, R^2=H, R^3=R^4=Ac
14a. R^1=H, R^2=OAc, R^3=R^4=Ac

Scheme 2. Sharpless asymmetric epoxidation of allylic alcohols using L-(+)-DET.



8. R^1=OBn, R^2=R^3=H, R^4=Bn

8b. R^1=OBn, R^2=R^3=H, R^4=Bn (60%)

Scheme 3. Sharpless asymmetric epoxidation of **8** using D-(−)-DIPT.

Table 1. Results of catalytic Sharpless asymmetric epoxidation (2.4 equiv of *t*-BuOOH, 0.20 equiv of Ti(O–*i*-Pr)$_4$ and 0.24 equiv of L-(+)-DET)

Entry	Substrate	Temp (°C)	Time (h)	Product	dr[a] 2*S*,3*R*:2*R*,3*S*	Yield[b] (%)
1[c]	**8**	−25 to 0	20		No reaction	
2[d]	**8**	−25 to 0	25	**8a**	99:1	62
3	**8**	−25 to 0	10	**8a**	99:1	70
4[e]	**8**	−25 to 0	10	**8b**	1:99	60
5	**9**	−25 to 0	15	**9a**	99:1	68
6	**10**	−25 to 0	6	**10a**	99:1	70
7[f]	**10**	−25 to 0	24	**10a**[g]	99:1	6
8[h]	**11**	−25 to 0	36	**11a**	99:1	60

[a] Determined by ^{1}H NMR of the crude material.
[b] Isolated yields of pure isomer.
[c] 2.4 equiv of *t*-BuOOH, 0.05 equiv of Ti(O–*i*-Pr)$_4$ and 0.06 equiv of L-(+)-DET were used.
[d] 2.4 equiv of *t*-BuOOH, 0.10 equiv of Ti(O–*i*-Pr)$_4$ and 0.12 equiv of L-(+)-DET were used.
[e] D-(−)-DIPT was used in this case.
[f] 3.0 equiv of *t*-BuOOH, 2.0 equiv of Ti(O–*i*-Pr)$_4$ and 2.5 equiv of L-(+)-DET were used.
[g] Compound **15** was isolated in 70% yield along with **10a**.
[h] 10% starting material was recovered.

diastereoselectivity as the main criteria, the protocol of catalytic SAE (2.4 equiv of *t*-BuOOH, 0.20 equiv of Ti(O–*i*-Pr)$_4$ and 0.24 equiv of L-(+)-DET) was extended to other allylic alcohols **9**–**14** using L-(+)-DET (Table 1). Compounds **12**, **13** and **14**, containing acyl protection, did not undergo SAE, even after prolonged hours of continuous stirring.

In the case of compound **10**, when Ti(O–*i*-Pr)$_4$ (2.0 equiv), L-(+)-DET (2.5 equiv) and *t*-BuOOH (3.0 equiv) were used, epoxide **10a** was isolated in 6%, along with tetrahydrofuran derivative **15** (Scheme 4) in 70% yield (Table 1 entry 7). The appearance of ten aromatic protons between δ 7.34 and 7.30 and four benzylic protons at δ 4.67–4.49 as a multiplet in the ^{1}H NMR spectrum of the cyclized compound **15**, indicated the presence of only two benzyl groups and the absence of a third one, which was present in the starting material **10**. It was also noticed that the epoxide protons were absent at δ 3.18–2.97 in **15**. Furthermore, its DEPT ^{13}C NMR spectrum showed the presence of 4-methylene carbons and 4-methine carbons in between δ 82.6 and 65.1. These spectroscopic data implied that intramolecular S_N2 type opening of the in situ formed epoxide occurred due to the participation of C-6-*O*-benzyl oxygen with concomitant debenzylation forming a tetrahydrofuran ring.

Based on the structure of **10a** there were two possible pathways for the formation of either of the two different tetrahydrofuran derivatives. This could be either 2,5-anhydro

derivative if the C-5 oxygen participates in epoxide opening or 3,6-anhydro derivative if the C-6 oxygen participates in epoxide opening. ^{1}H NMR and ^{13}C NMR spectrum signals assigned for **15** were reconfirmed on the basis of its HSQC spectrum. Its HMBC spectrum showed long range correlations as depicted in Figure 2. All the HMBC correlations in Figure 2 were in support of the structure of 3,6-anhydro derivative **15**, and ruled out the formation of 2,5-anhydro derivative based on the argument that the benzylic protons did not show any correlation with C-(6), suggesting the absence of $-CH_2Ph$ at this position.

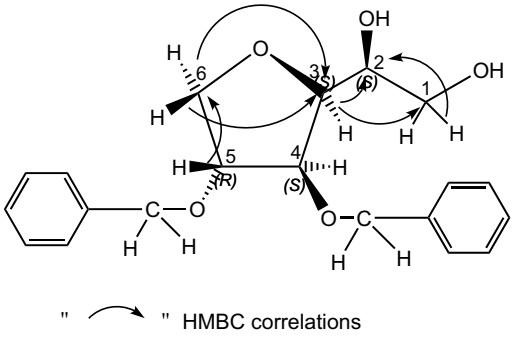


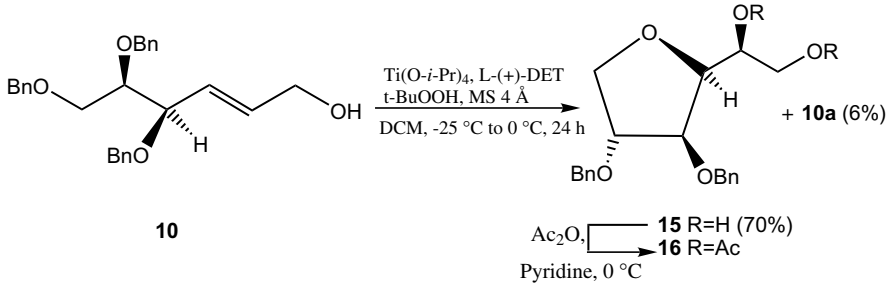
Figure 2. Selected HMBC correlations of **15**.

Structure **15** was further confirmed by preparing its diacetate derivative **16** (Scheme 4) whose ^{1}H NMR spectrum showed ddd ($J = 8.1$, 4.8 and 2.2 Hz) at δ 5.31 for carbinol proton at C-2. This multiplicity is only possible for H-2 proton in **16**. Thus, the detailed spectral study of the new tetrahydrofuran derivative **15** and its diacetate derivative **16** unequivocally established it as 3,6-anhydro-D-galactitol **15**. Our seemingly contradictory finding gained further support from Sharpless et al.'s earlier reports.[18] Here, although the author alluded the participation of oxygen atom of the C(6) benzyloxy group in the titanium-catalyzed ring opening of epoxide **IIIA**, during its formation by asymmetric epoxidation of its substrate to form a tetrahydrofuran derivative, the product was left uncharacterized.

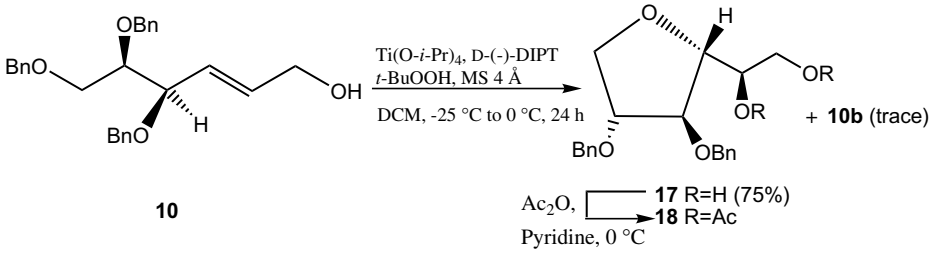
A thorough literature survey revealed that carbohydrates were extensively used as precursors in a tetrahydrofuran synthesis. The catalytic hydrogenation of glycals[19] and thioglycosides,[20] nitrous acid deamination of 2-amino-2-deoxyaldoses,[21] acid-catalyzed dehydration of acyclic alditols,[22] reduction of glycosyl halides,[23] dehydration of sugars catalyzed by pyridinium salts,[24] reductive cleavage of glycosides[25] and intramolecular cyclization of bromodeoxyaldonolactones and bromodeoxyalditols[26] are the literature reports for the preparation of anhydroalditols. Very few of these methods[26] were able to synthesize 3,6-anhydro-galactitols in an enatiomerically pure form and in good yields, which are not otherwise available in enantiomerically pure form from galactitol by simple treatment with acid.[27]

We also submitted compound **10** to SAE in the presence of D-(−)-DIPT (2.5 equiv) expecting to obtain 3,6-anhydro-L-galactitol (Scheme 5). The reaction was completed in 24 h furnishing the expected enantiomerically pure product **17** in 75% yield. The structure of this product was confirmed by comparing the spectral data with that of compound **15** and finally by preparing its diacetate derivative **18**.

These enantiomerically pure, highly functionalized tetrahydrofuran derivatives, which are of great value because of their industrial applications and biological properties,[28] can be effectively utilized as potential synthons for the preparation of biologically active compounds. We feel that



Scheme 4. Sharpless asymmetric epoxidation of **10** using L-(+)-DET.



Scheme 5. Sharpless asymmetric epoxidation of **10** using D-(−)-DIPT.

these moieties can be of great interest to a chemist as it has various sites of diversification to play around as illustrated in Figure 3.

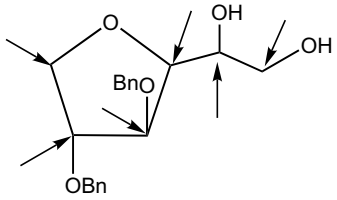


Figure 3. Arrows showing sites of diversification.

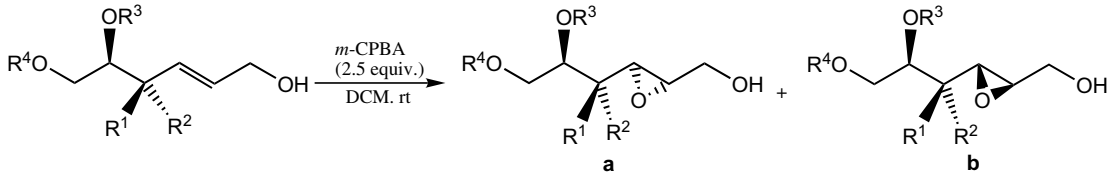
In light of the above findings, we were further interested to carry out epoxidation of all the above studied enantiomerically pure allylic alcohols (**8**–**14**) by *m*-CPBA with a view to compare the selectivity and yield of each reaction with that of SAE of the same substrate. The comparative study of epoxidation with *m*-CPBA (Scheme 6) was initiated using allylic alcohol **8**. The reaction was completed at room temperature producing chromatographically pure inseparable diastereomeric mixture of epoxide **8a**/**8b** (29/71) in 75% yield. All the allylic alcohols including acyl protected allylic alcohols **12**, **13** and **14**, which did not undergo SAE, underwent *m*-CPBA epoxidation furnishing the diastereomeric mixture of their respective epoxides (Table 2).

With these results in hand we came across a literature report that *m*-CPBA/KF complex (Camp's reagent) suspended in DCM can be used as a mild epoxidizing agent of olefins at room temperature to furnish the resulting epoxides in very good yield plausibly due to the inactivation of any acid-catalyzed side reaction. This reagent was used for diastereoselective one-step epoxidation of glycals.[29] Hence, we also tried this reagent for the epoxidation of the above studied allylic alcohols. However this method ended with almost similar results to that of *m*-CPBA mediated epoxidation apart from the non-participation of acetylated compounds **12**, **13** and **14** as they are less reactive allylic alcohols.

In order to ascertain the mechanistic pathway of the formation of 3,6-anhydrogalactitols **15** and **17**, compound (2*S*, 3*R*/2*R*,3*S*)-4,5,6-tri-*O*-benzyl-2,3-epoxy-D-galactitol **10a**/**10b**, an inseparable diastereomeric mixture of an epoxide prepared by *m*-CPBA mediated epoxidation of **10**, was stirred with *t*-BuOOH (3.0 equiv, 6.0 M solution in nonane) in the presence of Ti(O–*i*-Pr)$_4$ (2.0 equiv) and L-(+)-DET (2.5 equiv) in DCM under SAE conditions. This reaction mixture on continuous stirring for 12 h, provided a diastereomeric mixture of 3,6-anhydrogalactitols **15** or **17** (60/40,[30] ^{1}H NMR) confirming the involvement of epoxide intermediate during the cyclization process. It is worth mentioning here that absence of any one of the Sharpless reagents did not yield the 3,6-anhydrogalactitols **15** or **17**.

3. Conclusion

In conclusion, our approach towards the synthesis of 2,3-epoxyalcohols **III**, from Perlin aldehydes **I** is new and



8. R^1=OBn, R^2=R^3=H, R^4=Bn
9. R^1=R^3=H, R^2=OBn, R^4=Bn
10. R^1=OBn, R^2=H, R^3=R^4=Bn
11. R^1=H, R^2=OBn, R^3=R^4=Bn
12. R^1=OBn, R^2=H, R^3=Ac, R^4=Bn
13. R^1=OAc, R^2=H, R^3=R^4=Ac
14. R^1=H, R^2=OAc, R^3=R^4=Ac

8a/8b. R^1=OBn, R^2=R^3=H, R^4=Bn
9a/9b. R^1=R^3=H, R^2=OBn, R^4=Bn
10a/10b. R^1=OBn, R^2=H, R^3=R^4=Bn
11a/11b. R^1=H, R^2=OBn, R^3=R^4=Bn
12a/12b. R^1=OBn, R^2=H, R^3=Ac, R^4=Bn
13a/13b. R^1=OAc, R^2=H, R^3=R^4=Ac
14a/14b. R^1=H, R^2=OAc, R^3=R^4=Ac

Scheme 6. Epoxidation with *m*-CPBA.

Table 2. Results of *m*-CPBA mediate epoxidation at room temperature (30 °C)

Entry	Substrate	Time (h)	Product	dr[a] 2*S*,3*R*:2*R*,3*S*	Yield[b] (%)
1	**8**	4	**8a/8b**	29:71	75
2	**9**	3	**9a/9b**	58:42	73
3	**10**	3	**10a/10b**	60:40	70
4	**11**	3	**11a/11b**	28:72	80
5	**12**	5	**12a/12b**	32:68	67
6	**13**	120	**13a/13b**	66:34	44
7	**14**	115	**14a/14b**	37:63	45

[a] Determined by ^{1}H NMR of the crude material.
[b] Isolated yields of inseparable diastereomers.

proved to be a very simple and general method. This approach involved two steps for reaching the required 2,3-epoxyalcohol from **I**. The SAE reaction of **10** with *t*-BuOOH (3.0 equiv) in the presence of Ti(O–*i*-Pr)$_4$ (2.0 equiv), L-(+)-DET or D-(−)-DIPT (2.5 equiv) resulted in intramolecular S_N2 opening of the in situ formed 2,3-epoxy alcohol **10a** or **10b** by C(6) benzyloxy group with concomitant debenzylation resulting in enantiomerically pure, highly functionalized valuable tetrahydrofuran derivative **15** or **17**, which are important structural motifs found in various bioactive natural products such as antibiotics, terpene polyethers, *Annonaceous* acetogenins, etc.[31] Thus, by changing the ratio of Sharpless reagents we were able to obtain different products (2,3-epoxy alcohols or tetrahydrofurans) by applying the same reaction protocol. The extensive efforts in the preparation of polysubstituted tetrahydrofurans, not withstanding the established procedures in the literature, manifest their significance. All these 2,3-epoxy alcohols as well as 3,6-anhydro-galactitols reported herein were very stable and also prepared in gram scale (up to 10.0 g). These novel carbohydrate derivatives will certainly find wide applications in synthetic organic chemistry. Their further applications in synthetic and medicinal chemistry are currently underway in our laboratory.

4. Experimental

4.1. General

All the reactions were monitored by warming the $CeSO_4$ (1% in 2 M H_2SO_4) sprayed precoated silica gel TLC plates at 100 °C. NMR spectra were recorded on Bruker Avance DPX 200 FT, Bruker Robotics and Bruker DRX 300 Spectrometers at 200, 300 MHz (^{1}H) and 50, 75 MHz (^{13}C). For ^{13}C NMR reference, $CDCl_3$ appeared at 77.4 ppm, unless otherwise stated. Mass spectra were recorded on a JEOL SX 102/DA 6000 mass spectrometer using argon/xenon (6 kV, 100 mA) as the FAB gas. Organic solvents were dried by standard methods. Ti(O-*i*-Pr)$_4$, L-(+)-diethyl tartrate, D-(−)-diethyl tartrate and *t*-BuOOH were purchased from Aldrich chemical co. Allylic alcohols **8**–**14** were synthesized in the laboratory. IR spectra were recorded on Perkin–Elmer 881 and FTIR-8210 PC Shimadzu Spectrophotometers. Optical rotations were determined on an Autopol III polarimeter using a 1 dm cell at 28 °C in methanol or chloroform as the solvent; concentrations mentioned are in g/100 mL. Elemental analyses were carried out on Carlo-Erba-1108 and Vario EL III instruments. The minor diastereomers are marked as D in the assignment of ^{1}H NMR and ^{13}C NMR spectra of diastereoisomeric mixtures.

4.2. General procedure for catalytic Sharpless asymmetric epoxidation

A solution of Ti(O–*i*-Pr)$_4$ (0.029 mL, 0.10 mmol) and L-(+)-diethyltartrate (0.020 mL, 0.12 mmol) in CH_2Cl_2 (5 mL) was stirred at −25 °C for 0.5 h in the presence of MS 4 Å. To this mixture, a solution of compound **8** (164 mg, 0.5 mmol) in CH_2Cl_2 (5 mL) was added and the mixture stirred at the same temperature. After 0.5 h of stirring, a 6.0 M solution of *t*-BuOOH (0.20 mL, 1.2 mmol) was added and the temperature of the reaction raised to 0 °C and was left for stirring till the completion of the reaction. After completion, a 10% solution of tartaric acid (10 mL) was added to quench the reaction at 0 °C and stirred for 0.5 h. The solution was filtered through a Celite pad. The organic layer from the filtrate was separated using a separating funnel and concentrated to get the mixture residue. The residue was dissolved in Et_2O (20 mL) and stirred with 4% NaOH in brine solution (15 mL) at 0 °C for 0.75 h to hydrolyze and remove excess of diethyl tartrate. Later, the ether layer was separated using separating funnel, washed with brine, dried over Na_2SO_4 and concentrated to get the crude product. The crude product was purified by column chromatography to afford diastereomeric pure epoxide **8a**. A similar reaction protocol was adopted for compounds **9**, **10** and **11**.

Substrate **10** (1.0 equiv) was subjected to SAE with *t*-BuOOH (3.0 equiv) in the presence of Ti(O–*i*-Pr)$_4$ (2.0 equiv) and L-(+)-DET or D-(−)-DIPT (2.5 equiv) to obtain THF derivative **15** or **17**.

4.3. General procedure for epoxidation with *m*-CPBA

To a well stirred solution of allylic alcohol **8** in dry DCM at rt, *m*-CPBA (107 mg, 0.62 mmol) was added and was continued stirring at the same temperature till the completion of the reaction. Once the reaction was complete excess of saturated $NaHCO_3$ solution was added and left for stirring for 1 h to neutralize unused *m*-CPBA. Later, the reaction mixture was extracted with ethyl acetate (4 × 5 mL) and the combined organic layer was dried over anhydrous Na_2SO_4 and concentrated to give the crude product, which on column chromatography yielded a diastereomeric mixture of product **8a**/**8b** in 78% yield.

4.4. General procedure for epoxidation with *m*-CPBA-KF complex

A solution of *m*-CPBA (107 mg, 0.62 mmol) in dry CH_2Cl_2 (10 mL) was dried by passing it over Na_2SO_4. The resulting solution was then taken in the r.b. flask (100 mL) containing anhydrous KF (726.2 mg, 12.5 mmol) and left for stirring at room temperature for 30 min. To this, allylic alcohol **8** (82 mg, 0.25 mmol) was added slowly and stirring continued until the completion of the reaction. The reaction mixture after the completion of the reaction was filtered through Celite pad and concentrated under reduced pressure to get the crude product, which on column chromatography yielded inseparable diastereomeric mixture **8a**/**8b**.

4.4.1. (2*S*,3*R*)-4,6-Di-*O*-benzyl-2,3-epoxy-D-galactitol 8a. Oil, eluent for column chromatography: EtOAc/hexane (3/7, v/v), R_f 0.30 (1/1 EtOAc/hexane); $[\alpha]_D$ −26.47 (*c* 0.170, $CHCl_3$); IR (neat, cm^{-1}): 3403 (O–H str), 3031 (=C–H str), 2923, 2869 (–C–H str), 1495, 1454 (C=C str), 1218 (C–O str of epoxide), 1093 (C–O str); ^{1}H NMR (200 MHz, $CDCl_3$): δ 7.32–7.25 (m, 10H, ArH), 4.68–4.50 (m, 4H, 2 × CH_2Ph), 3.93 (m, 1H, H-5), 3.76 (dd, $J_{1a,1b} = 12.7$ Hz and $J_{1a,2} = 2.6$ Hz, 1H, H-1a), 3.62–3.47

(m, 4H, H-1b, H-6a, H-6b and H-4), 3.14 (dd, $J_{3,4} = 5.1$ Hz and $J_{3,2} = 2.2$ Hz, 1H, H-3), 3.08 (m, 1H, H-2); ^{13}C NMR (50 MHz, $CDCl_3$): δ 138.3, 138.2 (Ar qC), 128.8, 128.3, 128.2 (ArC), 77.3 (C-4), 74.0, 73.8 ($2 \times CH_2Ph$), 71.2 (C-5), 71.0 (C-1), 61.5 (C-6), 57.2 (C-3), 55.1 (C-2); FAB MS calcd for $C_{20}H_{24}O_5$ m/z 344; found 345 $[M+1]^{+\cdot}$, 325, 253 $[M-CH_2Ph]^{+\cdot}$, 181. Elemental analysis calcd for $C_{20}H_{24}O_5 \cdot H_2O$ (362.43) C, 66.28; H, 7.23. Found: C, 66.91; H, 7.43.

4.4.2. (2*R*,3*S*)-4,6-Di-*O*-benzyl-2,3-epoxy-D-galactitol 8b. Oil, eluent for column chromatography: EtOAc/hexane (3/7, v/v), R_f 0.32 (1/1 EtOAc/hexane); $[\alpha]_D = -16.4$ (c 0.073, $CHCl_3$); IR (neat, cm^{-1}): 3431 (O–H str), 3029 (=C–H str), 2922 (–C–H str), 1653, 1495, 1456 (C=C str), 1218 (C–O str of epoxide), 1091 (C–O str); ^{1}H NMR (200 MHz, $CDCl_3$): δ 7.40–7.28 (m, 10H, ArH), 4.88–4.49 (m, 4H, $2 \times CH_2Ph$), 3.87 (m, 1H, H-5), 3.72 (dd, $J_{1a,1b} = 12.6$ Hz and $J_{1a,2} = 3.3$ Hz, 1H, H-1a), 3.61–3.53 (m, 3H, H-1b, H-6a and H-6b), 3.31 (dd, $J_{4,3} = 7.1$ Hz and $J_{4,5} = 4.7$ Hz, 1H, H-4), 3.18 (dd, $J_{3,4} = 7.1$ Hz and $J_{3,2} = 2.2$ Hz, 1H, H-3), 2.97 (dd, $J = 5.9$ Hz and $J = 3.5$ Hz, 1H, H-2); ^{13}C NMR (50 MHz, $CDCl_3$): δ 138.2, 138.0 (Ar qC), 129.0, 128.8, 128.4, 128.2 (ArC), 80.0 (C-4), 74.0, 72.8 ($2 \times CH_2Ph$), 71.5 (C-5), 70.7 (C-1), 61.5 (C-6), 56.9 (C-2), 54.8 (C-3); FAB MS calcd for $C_{20}H_{24}O_5$ m/z 344; found 345, 325 $[M-17]^{+\cdot}$, 253 $[M-CH_2Ph]^{+\cdot}$, 221, 181. Elemental analysis calcd for $C_{20}H_{24}O_5 \cdot H_2O$ (362.43) C, 66.28; H, 7.23. Found: C, 66.69; H, 7.49.

4.4.3. (2*S*,3*R*)-4,6-Di-*O*-benzyl-2,3-epoxy-D-glucitol 9a. Oil, eluent for column chromatography: EtOAc/hexane (3/7, v/v), R_f 0.37 (1/1 EtOAc/hexane); $[\alpha]_D = +12.1$ (c 0.066, $CHCl_3$); IR (neat, cm^{-1}): 3398 (O–H str), 3031 (=C–H str), 2921, 2870 (–C–H str), 1655, 1605, 1496 (C=C str), 1214 (C–O str of epoxide), 1096 (C–O str); ^{1}H NMR (200 MHz, $CDCl_3$): δ 7.30–7.25 (m, 10H, ArH), 4.82–4.48 (m, 4H, $2 \times CH_2Ph$), 3.90 (m, 1H, H-5), 3.74 (dd, $J_{1a,1b} = 12.5$ Hz and $J_{1a,2} = 3.3$ Hz, 1H, H-1a), 3.66–3.59 (m, 2H, H-1b and H-6a), 3.57 (dd, $J_{6b,6a} = 10.6$ Hz and $J_{6b,5} = 4.6$ Hz, 1H, H-6b), 3.25 (br t, $J = 6.9$ Hz, 1H, H-4), 3.16 (dd, $J_{3,4} = 7.0$ Hz and $J_{3,2} = 2.0$ Hz, 1H, H-3), 3.00 (m, 1H, H-2); ^{13}C NMR (50 MHz, $CDCl_3$): δ 138.3, 138.0 (Ar qC), 128.9, 128.8, 128.3, 128.2 (ArC), 80.0 (C-4), 73.9 (C-1), 72.8 (CH_2Ph), 71.1 (C-5), 71.0 (CH_2Ph), 61.7 (C-6), 57.2 (C-3), 55.5 (C-2); FAB MS calcd for $C_{20}H_{24}O_5$ m/z 344; found 345 $[M+1]^{+\cdot}$, 327 $[M-17]^{+\cdot}$ 253 $[M-CH_2Ph]^{+\cdot}$, 203, 181. Elemental analysis calcd for $C_{20}H_{24}O_5 \cdot H_2O$ (362.43) C, 66.28; H, 7.23. Found: C, 66.17; H, 6.83.

4.4.4. (2*S*,3*R*)-4,5,6-Tri-*O*-benzyl-2,3-epoxy-D-galactitol 10a. Oil, eluent for column chromatography: EtOAc/hexane (3/22, v/v), R_f 0.42 (3/7 EtOAc/hexane); $[\alpha]_D = -20.3$ (c 0.123, $CHCl_3$); IR (neat, cm^{-1}): 3413 (O–H str), 3065, 3013 (=C–H str), 2933, 2875 (–C–H str), 1606, 1456, 1455 (C=C str), 1217 (C–O str of epoxide), 1091 (C–O str); ^{1}H NMR (200 MHz, $CDCl_3$): δ 7.31–7.25 (m, 15H, ArH), 4.76–4.48 (m, 6H, $3 \times CH_2Ph$), 3.82–3.75 (m, 1H, H-4), 3.67–3.62 (m, 3H, H-1a, H-1b, H-5), 3.59–3.55 (m, 1H, H-6a), 3.46 (dd, $J_{6b,6a} = 12.6$ Hz and $J_{6b,5} = 4.1$ Hz 1H, H-6b), 3.14 (dd, $J_{3,4} = 4.5$ Hz and $J_{3,2} = 2.0$ Hz 1H, H-3), 3.06–3.05 (m, 1H, H-2); ^{13}C NMR (50 MHz, $CDCl_3$): δ 138.2, 138.0 (Ar qC), 128.3, 128.1, 128.0, 127.8, 127.7 (ArC), 78.2 (C-4), 76.6 (C-5), 73.6, 73.4, 73.3 ($3 \times CH_2Ph$), 69.1 (C-1), 61.3 (C-6), 56.8 (C-3), 54.8 (C-2); FAB MS calcd for $C_{27}H_{30}O_5$ m/z 434; found 435 $[M+1]^{+\cdot}$, 343 $[M-CH_2Ph]^{+\cdot}$.

4.4.5. (2*S*,3*R*/2*R*,3*S*)-4,5,6-Tri-*O*-benzyl-2,3-epoxy-D-galactitol 10a/10b. Oil, eluent for column chromatography: EtOAc/hexane (3/22, v/v), R_f 0.42 (3/7 EtOAc/hexane); IR (neat, cm^{-1}): 3446 (O–H str), 3065, 3030 (=C–H str), 2919 (–C–H str), 1496, 1454 (C=C str), 1216 (C–O str of epoxide), 1097 (C–O str); ^{1}H NMR (200 MHz, $CDCl_3$): δ 7.31–7.25 (m, 15H, ArH), 4.77–4.48 (m, 6H, $3 \times CH_2Ph$), 3.82–3.30 (m, 6H, H-1, H-4, H-5 and H-6), 3.20 (dd, $J_{3,4} = 6.8$ Hz and $J_{3,2} = 2.2$ Hz 1H, Hβ-3), 3.14 (dd, $J_{3,4} = 4.6$ Hz and $J_{3,2} = 2.2$ Hz 1H, Hα-3), 3.07 (m, 1H, Hα-2), 2.95 (m, 1H, Hβ-2); ^{13}C NMR (50 MHz, $CDCl_3$): δ 138.5, 138.4 (Ar qC), 128.7, 128.4, 128.3 128.0 (ArC), 79.6 (C-4), 78.6 (C_D-4), 77.0 (C-5), 74.0, 73.8, 73.6 ($3 \times CH_2Ph$), 69.6 (C-1), 61.6 (C-6), 57.1 (C-3), 56.8 (C_D-3), 55.1 (C-2), 54.8 (C_D-2); FAB MS calcd for $C_{27}H_{30}O_5$ m/z 434; found 434 $[M]^{+\cdot}$, 343 $[M-CH_2Ph]^{+\cdot}$, 271, 253 $[M+1-2CH_2Ph]^{+\cdot}$, 231, 189, 165. Elemental analysis calcd for $C_{27}H_{30}O_5$ (434.54) C, 74.63; H, 6.95. Found: C, 74.61; H, 7.00.

4.4.6. (2*S*,3*R*)-4,5,6-Tri-*O*-benzyl-2,3-epoxy-D-glucitol 11a. Oil, eluent for column chromatography: EtOAc/hexane (3/17, v/v), R_f 0.38 (3/7 EtOAc/hexane); $[\alpha]_D = +10.5$ (c 0.057, $CHCl_3$); IR (neat, cm^{-1}): 3432 (O–H str), 3063, 3031 (=C–H str), 2924, 2865 (–C–H str), 1604, 1496, 1454 (C=C str), 1211 (C–O str of epoxide), 1097 (C–O str); ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.38–7.28 (m, 15H, ArH), 4.85–4.54 (m, 6H, $3 \times CH_2Ph$), 3.82–3.71 (m, 3H, H-1a, H-1b, H-5), 3.67–3.53 (m, 2H, H-6a, H-6b), 3.45 (br t, $J = 6.0$ Hz 1H, H-4), 3.22 (dd, $J_{3,4} = 9.0$ Hz and $J_{3,2} = 3.0$ Hz 1H, H-3), 3.01 (ddd, $J_{2,1a} = 9.0$ Hz, $J_{2,1b} = 6.0$ and $J_{2,3} = 3.0$ Hz 1H, H-2); ^{13}C NMR (50 MHz, $CDCl_3$): δ 138.5, 138.4 (Ar qC), 128.8, 128.7, 128.3, 128.2, 128.1, 128.0 (ArC), 79.4 (C-4), 78.9 (C-5), 73.8, 73.1, 73.0 ($3 \times CH_2Ph$), 69.2 (C-1), 61.6 (C-6), 57.1 (C-3), 55.7 (C-2); ES MS Calcd for $C_{27}H_{30}O_5$ m/z 434; found 435 $[M+1]^{+\cdot}$, 343 $[M-CH_2Ph]^{+\cdot}$.

4.4.7. (2*R*,3*S*)-4,5,6-Tri-*O*-benzyl-2,3-epoxy-D-glucitol 11b. It was isolated as an oil from the mixture of **11a**/**11b** during its repeated silica gel column chromatographic purification using EtOAc/hexane (3/22, v/v) as eluent, R_f 0.48 (3/7 EtOAc/hexane); $[\alpha]_D = -22.8$ (c 0.136, $CHCl_3$); IR (neat, cm^{-1}): 3446 (O–H str), 3029 (=C–H str), 2920, 2869 (–C–H str), 1603, 1496, 1454 (C=C str), 1216 (C–O str of epoxides), 1096 (C–O str); ^{1}H NMR (200 MHz, $CDCl_3$): δ 7.31–7.26 (m, 15H, ArH), 4.77–4.51 (m, 6H, $3 \times CH_2Ph$), 3.81–3.39 (m, 6H, H-1, H-4, H-5 and H-6), 3.20 (dd, $J_{3,4} = 6.8$ Hz and $J_{3,2} = 1.6$ Hz, 1H, H-3), 2.98 (m, 1H, H-2); ^{13}C NMR (50 MHz, $CDCl_3$): δ 138.6 (Ar qC), 128.8, 128.3, 128.1 (ArC), 79.5 (C-4), 79.0 (C-5), 73.8, 73.1, 73.0 ($3 \times CH_2Ph$), 69.3 (C-1), 61.7 (C-6), 57.1 (C-3), 55.8 (C-2); FAB MS calcd for $C_{27}H_{30}O_5$ m/z 434;

found 435 $[M+1]^{+\cdot}$, 419 $[M+2-H_2O]$ 348 $[M-CH_2Ph]^{+\cdot}$, 253 $[M+1-2\times CH_2Ph]^{+\cdot}$, 221, 207, 181. Elemental analysis calcd for $C_{27}H_{30}O_5{\cdot}0.5H_2O$ (443.55) C, 73.11; H, 7.04. Found: C, 72.80; H, 6.56.

4.4.8. (2*S*,3*R*/2*R*,3*S*)-4,6-Di-*O*-benzyl-5-*O*-acetyl-2,3-epoxy-D-galactitol 12a/12b. Oil, eluent for column chromatography, 3:17 EtOAc/hexane v/v, R_f 0.48 (2/3 EtOAc/hexane); IR (neat, cm^{-1}): 3467 (O–H str), 3017 (=C–H str), 2924, 2871 (–C–H str), 1738 (C=O str), 1496, 1454 (C=C str), 1374 (C–H def of CH_3), 1238 (C–O str of epoxides), 1057 (C–O str); ^1H NMR (200 MHz, $CDCl_3$): δ 7.31–7.25 (m, 10H, ArH), 5.28–5.20 (m, 1H, H-5), 4.68–4.47 (m, 4H, $2\times CH_2Ph$), 3.75–3.37 (m, 5H, H-4, H-1a, H-1b, H-6a and H-6b), 3.08 (dd, $J_{3,4}=9.0$ Hz and $J_{3,2}=2.6$ Hz, 1H, H-3), 3.03–2.96 (m, 1H, H-2), 2.09 (s, 3H, $COCH_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ 171.0 ($COCH_3$), 138.2, 138.1 (Ar qC), 128.8, 128.2 (ArC), 78.4 (C-5), 75.5 (C_D-5), 74.3 (CH_2Ph), 73.7 (CH_2Ph_D), 73.1 (C-4), 72.4 (C_D-4), 72.7 (CH_2Ph), 68.5 (C-1), 68.1 (C_D-1), 61.8 (C-6), 57.0 (C-3), 56.4 (C_D-3), 55.0 (C-2), 54.6 (C_D-2), 21.4 ($COCH_3$); FAB MS calcd for $C_{22}H_{26}O_6$ m/z 386; found 387 $[M+1]^{+\cdot}$, 369 $[M+1-H_2O]^{+\cdot}$, 355 $[M-CH_2OH]^{+\cdot}$, 295 $[M-CH_2Ph]^{+\cdot}$, 279, 181. Elemental analysis calcd for $C_{22}H_{26}O_6{\cdot}0.5H_2O$ (395.46) C, 66.81; H, 6.88. Found: C, 66.60; H, 6.83.

4.4.9. (2*S*,3*R*/2*R*,3*S*)-4,5,6-Tri-*O*-acetyl-2,3-epoxy-D-galactitol (13a/13b). Oil, eluent for column chromatography: EtOAc/hexane (7/13, v/v), R_f 0.23 (1/1 EtOAc/hexane); IR (neat, cm^{-1}): 3478 (O–H str), 2934 (C–H str), 1745 (C=O str), 1374 (C–H def of CH_3), 1225 (C–O str); ^1H NMR (200 MHz, $CDCl_3$): δ 5.42–5.31 (m, 1H, H-5), 5.06 (br t, $J_{4,3=5}=5.2$ Hz, 1H, H-4), 5.03 (br t, $J_{4,3=5}=4.0$ Hz, 1H, H_D-4), 4.38 (dd, $J_{6a,6b}=12.0$ Hz and $J_{6a,5}=4.1$ Hz, 1H, H-6a), 4.32 (dd, $J_{6a,6b}=11.0$ Hz and $J_{6a,5}=4.9$ Hz, 1H, H_D-6a), 4.12 (dd, $J_{6b,6a}=12.0$ Hz and $J_{6b,5}=2.5$ Hz, 1H, H-6b), 4.09 (dd, $J_{6b,6a}=11.0$ Hz and $J_{6b,5}=2.5$ Hz, 1H, H_D-6b), 3.74–3.62 (m, 2H, H-1a and H-1b), 3.20 (dd, $J_{3,4}=5.4$ Hz and $J_{3,2}=2.2$ Hz, 1H, H-3), 3.12–3.08 (m, 1H, H-2), 2.13, 2.12, 2.10 ($3\times OCOCH_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ 170.8, 170.5 and 170.2 ($3\times COCH_3$), 71.1 (C-4), 70.7 (C-5), 70.1 (C_D-4), 70.0 (C_D-5), 62.3 (C-1), 62.0 (C_D-1), 61.0 (C-6), 60.9 (C_D-6), 56.8 (C_D-3), 56.1 (C-3), 54.3 (C-2), 52.7 (C_D-2), 21.0 ($3\times OCOCH_3$); FAB MS calcd for $C_{12}H_{18}O_8$ m/z 290; found 291 $[M+1]^{+\cdot}$, 259 $[M-CH_2OH]^{+\cdot}$, 231 $[M-OCOCH_3]^{+\cdot}$, 219, 202, 165. Elemental analysis calcd for $C_{12}H_{18}O_8{\cdot}H_2O$ (308.29) C, 46.75; H, 6.53. Found: C, 46.85; H, 5.77.

4.4.10. (2*R*,3*S*)-4,5,6-Tri-*O*-acetyl-2,3-epoxy-D-galactitol 13b. Compound **13b** was isolated as an oil from the mixture of **13a/13b** during its repeated silica gel column chromatographic purification using EtOAc/hexane (7/13, v/v), as eluent, R_f 0.23 (1/1 EtOAc/hexane); IR (neat, cm^{-1}): 3466 (O–H str), 2924 (C–H str), 1746 (C=O str), 1374 (C–H def of CH_3), 1225 (C–O str); ^1H NMR (200 MHz, $CDCl_3$): δ 5.38–5.31 (m, 1H, H-5), 5.06 (br t, $J_{4,3=5}=5.2$ Hz, 1H, H-4), 4.38 (dd, $J_{6a,6b}=12.1$ Hz and $J_{6a,5}=4.1$ Hz, 1H, H-6a), 4.12 (dd, $J_{6b,6a}=12.1$ Hz and $J_{6b,5}=6.2$ Hz, 1H, H-6b), 3.87 (dd, $J_{1a,1b}=12.8$ Hz and $J_{1a,2}=2.8$ Hz, 1H, H-1a), 3.71 (dd, $J_{1b,1a}=12.8$ Hz and $J_{1b,2}=3.3$ Hz, 1H, H-1b), 3.19 (dd, $J_{3,4}=5.4$ Hz and $J_{3,2}=2.1$ Hz, 1H, H-3), 3.08 (dd, $J_{2,1}=5.5$ Hz and $J_{2,3}=2.8$ Hz, 1H, H-2), 2.13, 2.12, 2.07 ($3\times OCOCH_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ 170.8, 170.5 and 170.2 ($3\times COCH_3$), 71.1 (C-4), 70.7 (C-5), 62.3 (C-1), 61.0 (C-6), 56.1 (C-3), 54.3 (C-2), 21.0 ($3\times OCOCH_3$); FAB MS calcd for $C_{12}H_{18}O_8$ m/z 290; found 291 $[M+1]^{+\cdot}$, 273 $[M-H_2O]^{+\cdot}$, 259 $[M-CH_2OH]^{+\cdot}$, 231 $[M-OCOCH_3]^{+\cdot}$, 173 $[M-2OCOCH_3]^{+\cdot}$.

4.4.11. (2*S*,3*R*/2*R*,3*S*)-4,5,6-Tri-*O*-acetyl-2,3-epoxy-D-glucitol 14a/14b. Oil, eluent for column chromatography: EtOAc/hexane (7/13) v/v, R_f 0.23 (1/1 EtOAc/hexane); IR (neat, cm^{-1}): 3486 (O–H str), 2930 (C–H str), 1745 (C=O str), 1373 (C–H def of CH_3), 1219 (C–O str of epoxides), 1047 (C–O str); ^1H NMR (200 MHz, $CDCl_3$): δ 5.36–5.25 (m, 1H, H-5), 5.02 (br t, $J_{4,3=5}=5.8$ Hz, 1H, H-4), 4.36 (dd, $J_{6a,6b}=12.2$ Hz and $J_{6a,5}=3.4$ Hz, 1H, H-6a), 4.19 (dd, $J_{6b,6a}=12.2$ Hz and $J_{6b,5}=6.2$ Hz, 1H, H-6b), 3.88 (dd, $J_{1a,1b}=12.8$ Hz and $J_{1a,2}=2.8$ Hz, 1H, H-1a), 3.69 (dd, $J_{1b,1a}=12.8$ Hz and $J_{1b,2}=3.7$ Hz, 1H, H-1b), 3.24 (dd, $J_{3,4}=5.8$ Hz and $J_{3,2}=2.0$ Hz, 1H, H-3), 3.19 (m, 1H, H_D-3), 3.09 (m, 1H, H-2), 2.10, 2.08, 2.07 ($3\times OCOCH_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ 171.0, 170.4 and 170.1 ($3\times COCH_3$), 71.2 (C-4), 71.0 (C_D-4), 70.8 (C-5), 70.8 (C_D-5), 62.2 (C-1), 62.1 (C_D-1), 61.1 (C-6), 61.0 (C_D-6), 56.5 (C-3), 54.0 (C-2), 52.6 (C_D-2), 21.1 ($3\times OCOC_DH_3$), 21.0 ($3\times OCOCH_3$); FAB MS calcd for $C_{12}H_{18}O_8$ m/z 290; found 291 $[M+1]^{+\cdot}$, 259 $[M-CH_2OH]^{+\cdot}$, 231 $[M-OCOCH_3]^{+\cdot}$, 219, 154. Elemental analysis calcd for $C_{12}H_{18}O_8{\cdot}H_2O$ (308.29) C, 46.75; H, 6.53. Found: C, 47.00; H, 5.86.

4.4.12. 3,6-Anhydro-4,5-di-*O*-benzyl-D-galactitol 15. Oil, eluent for column chromatography: EtOAc/hexane (7/13, v/v), $[\alpha]_D=+25.00$ (c 0.140, $CHCl_3$); R_f 0.18 (3/7 EtOAc/hexane); IR (neat, cm^{-1}): 3429 (O–H str), 3066, 3015 (=C–H str), 2928 (–C–H str), 1496, 1455 (C=C str), 1217, 1087 (C–O str); ^1H NMR (300 MHz, $CDCl_3$): δ 7.34–7.30 (m, 10H, ArH), 4.67–4.49 (m, 4H, $2\times CH_2Ph$), 4.16 (m, 1H, H-4), 4.13–4.10 (m, 2H, H-5 and H-6a), 4.03–3.98 (m, 2H, H-2 and H-3), 3.89–3.79 (m, 2H, H-6b and H-1a), 3.69 (dd, $J_{1b,1a}=11.1$ Hz and $J_{1b,2}=3.9$ Hz, 1H, H-1b); ^{13}C NMR (50 MHz, $CDCl_3$): δ 137.9, 137.8 (Ar qC), 129.0, 128.9, 128.5, 128.3, 128.2, 128.0 (ArC), 82.70 (C-5), 82.0 (C-4), 80.9 (C-3), 72.6 (CH_2Ph), 72.1 (C-6), 71.9 (CH_2Ph), 70.1 (C-2), 65.1 (C-1); FAB MS calcd for $C_{20}H_{24}O_5$ m/z 344; found 345 $[M+1]^{+\cdot}$, 325, 253 $[M-CH_2Ph]^{+\cdot}$, 203, 181, 154. Elemental analysis calcd for $C_{20}H_{24}O_5{\cdot}H_2O$ (362.43) C, 66.28; H, 7.23. Found: C, 66.49; H, 6.89.

4.4.13. 3,6-Anhydro-1,2-di-*O*-acetyl-4,5-di-*O*-benzyl-D-galactitol 16. Oil, eluent for column chromatography: EtOAc/hexane (1/9, v/v), $[\alpha]_D=+15.55$ (c 0.090, $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$): δ 7.39–7.26 (m, 10H, ArH), 5.31 (ddd, $J_{2,3}=8.1$ Hz, $J_{2,1b}=4.8$ Hz and $J_{2,1a}=2.2$ Hz, 1H, H-2), 4.65 (dd, $J_{1a,1b}=12.3$ Hz and $J_{1a,2}=2.2$ Hz, 1H, H-1a), 4.56–4.39 (m, 4H, $2\times CH_2Ph$), 4.19 (dd, $J_{1b,1a}=12.0$ Hz and $J_{1b,2}=4.8$ Hz, 1H, H-1b), 4.18 (m, 1H. H-4), 4.12–4.01 (m, 2H, H-3 and H-5), 3.99–3.94 (m, 1H, H-6a), 3.87 (dd, $J_{6b,6a}=12.8$ Hz and $J_{6b,5}=$

4.4 Hz, 1H, H-6b), 2.05 (s, 3H, $COCH_3$), 1.94 (s, 3H, $COCH_3$); ^{13}C NMR (50 MHz, $CDCl_3$): δ 171.2, 170.0 ($2\times COCH_3$), 137.9, 137.6 (Ar qC), 128.9, 128.5, 128.4, 128.0 (ArC), 81.6 (C-5), 81.2 (C-4), 78.7 (C-2), 72.5 (CH_2Ph), 72.3 (C-6), 71.8 (CH_2Ph), 69.5 (C-3), 63.7 (C-1), 21.3, 21.2 ($2\times COCH_3$).

4.4.14. 3,6-Anhydro-4,5-di-*O*-benzyl-L-galactitol (17). Oil, eluent for column chromatography: EtOAc/hexane (8/17, v/v), R_f 0.20 (1/1 EtOAc/hexane); $[\alpha]_D = +2.0$ (*c* 0.100, $CHCl_3$); IR (neat, cm^{-1}): 3422 (O–H str), 3066, 3015 (=C–H str), 2927, 2857 (–C–H str), 1496, 1456 (C=C str), 1216, 1098 (C–O str); ^1H NMR (200 MHz, $CDCl_3$): δ 7.38–7.28 (m, 10H, ArH), 4.54–4.49 (m, 4H, $2\times CH_2Ph$), 4.18 (m, 1H, H-4), 4.09–4.00 (m, 2H, H-5 and H-6a), 3.91–3.80 (m, 3H, H-2, H-3 and H-1a), 3.70 (dd, $J_{6b,6a} = 11.6$ Hz and $J_{6b,5} = 3.8$ Hz, 1H, H-6b); 3.62 (dd, $J_{1b,1a} = 11.8$ Hz and $J_{1b,2} = 5.0$ Hz, 1H, H-1b); ^{13}C NMR (50 MHz, $CDCl_3$): δ 138.0, 137.7 (Ar qC), 129.0, 128.9, 128.3, 128.2 (ArC), 85.5 (C-5), 83.7 (C-4), 83.0 (C-3), 72.2 (CH_2Ph), 71.8 (C-6), 71.7 (C-2), 71.6 (CH_2Ph), 64.0 (C-1); FAB MS calcd for $C_{20}H_{24}O_5$ *m*/*z* 344; found 345 $[M+1]^{+\cdot}$, 323, 281, 257, 239. Elemental analysis calcd for $C_{20}H_{24}O_5\cdot H_2O$ (362.43) C, 66.28; H, 7.23. Found: C, 66.38; H, 7.36.

4.4.15. 3,6-Anhydro-1,2-di-*O*-acetyl-4,5-di-*O*-benzyl-L-galactitol (18). Oil, eluent for column chromatography EtOAc/hexane (1/9, v/v), $[\alpha]_D = +19.1$ (*c* 0.068, $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$): δ 7.39–7.28 (m, 10H, ArH), 5.22 (ddd, $J_{2,3} = 7.5$ Hz, $J_{2,1b} = 5.7$ Hz and $J_{2,1a} = 2.6$ Hz, 1H, H-2), 4.56–4.49 (m, 4H, $2\times CH_2Ph$), 4.48 (dd, $J_{1a,1b} = 10.0$ Hz and $J_{1a,2} = 2.5$ Hz, 1H, H-1a), 4.17 (dd, $J_{1b,1a} = 12.2$ Hz and $J_{1b,2} = 5.6$ Hz, 1H, H-1b), 4.05–3.99 (m, 4H, H-3, H-4, H-5 and H-6a), 3.92 (dd, $J_{6b,6a} = 10.1$ Hz and $J_{6b,5} = 4.0$ Hz, 1H, H-6b), 2.05 (s, 3H, $COCH_3$), 2.00 (s, 3H, $COCH_3$).

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References

1. (a) Csuk, R.; Glänzer, B. I.; Fürstner, A.; Weidmann, H.; Formacek, V. *Carbohydr. Res.* **1986**, *157*, 235–241; (b) Moskal, J.; Leusen, A. M. V. *J. Org. Chem.* **1986**, *51*, 4131–4139; (c) Fernandez-Mayoralas, A.; Marra, A.; Trumtel, M.; Veyrieres, A.; Sinaÿ, P. *Carbohydr. Res.* **1989**, *188*, 81–95; (d) Fürstner, A.; Weidmann, H. *J. Org. Chem.* **1990**, *55*, 1363–1366; (e) Román, E.; Serrano, J. A.; Cuéllar, M. E.; Marfil, A.; Galbis, J. A. *J. Carbohydr. Chem.* **1992**, *11*, 1–19; (f) Heras-López, A. M.; Pino-González, M. S.; Sarabia-García, F.; López-Herrera, F. J. *J. Org. Chem.* **1998**, *63*, 9630–9634.
2. (a) Lichtenthaler, F. W. *Pure Appl. Chem.* **1978**, *50*, 1343–1362; (b) Fraser-Reid, B.; Anderson, R. C.. *Carbohydrate Derivatives in the Asymmetric Synthesis of Natural Products*. In *Fortschr. Chem. Org. Naturst.*; Springer: Wien, 1980, p 1; (c) Vasella, A. Chiral Building Blocks from Sugars. In *Modern Synthetic Methods*; Scheffold, R., Ed.; Salle & Sauerländer: Frankfurt, 1980; p 173; (d) Hanessian, S. *Total Synthesis of Natural Products: The Chiron Approach*; Pergamon: New York, 1983; (e) Inch, T. D. *Tetrahedron* **1984**, *40*, 3161–3213; (f) Casiraghi, G.; Zanardi, F.; Rassu, G.; Spanu, P. *Chem. Rev.* **1995**, *95*, 1677–1716; (g) Hudlicky, T. *Chem. Rev.* **1996**, *96*, 3–30; (h) Wu, Y.-L.; Wu, W.-L.; Li, Y.-L.; Sun, X.-L.; Peng, Z.-H. *Pure Appl. Chem.* **1996**, *68*, 727–734; (i) H-López, A. M.; P-González, M. S.; S-García, F.; L-Herrera, F. J. *J. Org. Chem.* **1998**, *63*, 9630–9634.
3. (a) Gonzalez, F.; Lesage, S.; Perlin, A. S. *Carbohydr. Res.* **1975**, *42*, 267–274; (b) Sagar, R.; Pathak, R.; Shaw, A. K. *Carbohydr. Res.* **2004**, *339*, 2031–2035; (c) Saquib, M.; Sagar, R.; Shaw, A. K. *Carbohydr. Res.* **2006**, *341*, 1052–1056.
4. (a) Horton, D.; Liav, A. *Carbohydr. Res.* **1972**, *24*, 105–113; (b) Kaluza, Z.; Chmielewski, M.; Pedersen, E. B. *Heterocycles* **1988**, *27*, 1313–1316; (c) Wengel, J.; Lau, J.; Pedersen, E. B. *Synthesis* **1989**, 829–832; (d) Lau, J.; Pedersen, E. B. *Chem. Scr.* **1989**, *29*, 67–70; (e) Walczak, K.; Pedersen, E. B. *Synthesis* **1991**, 959–962; (f) Lau, J.; Wengel, J.; Pedersen, E. B.; Vestergaard, B. F. *Synthesis* **1991**, 1183–1190; (g) Hirata, N.; Yamagiwa, Y.; Kamikawa, T. *J. Chem. Soc. Perkin Trans. 1* **1991**, 2279–2280; (h) Wengel, J.; Pedersen, E. B.; Vestergaard, B. F. *Synthesis* **1992**, 319–322; (i) Lellouche, J.-P.; Quinton, P. *Synth. Commun.* **1994**, *24*, 1979–1988; (j) Kitajima, M.; Shirakawa, S.; Abdel-moty, S. G. A.; Takayama, H.; Sakai, S.-i.; Aimi, N.; Stockigt, J. *Chem. Pharm. Bull.* **1996**, *44*, 2195–2197.
5. Pathak, R.; Shaw, A. K.; Bhaduri, A. P.; Chandrasekhar, K. V. G.; Srivastava, A.; Srivastava, K. K.; Chaturvedi, V.; Srivastava, R.; Srivastava, B. S.; Arora, S.; Sinha, S. *Bioorg. Med. Chem.* **2002**, *10*, 1695–1702.
6. Pathak, R.; Pant, C. S.; Shaw, A. K.; Bhaduri, A. P.; Gaikward, A. N.; Sinha, S.; Srivastava, A.; Srivastava, K. K.; Chaturvedi, V.; Srivastava, R.; Srivastava, B. S. *Bioorg. Med. Chem.* **2002**, *10*, 3187–3196.
7. Sagar, R.; Singh, P.; Kumar, R.; Maulik, P. R.; Shaw, A. K. *Carbohydr. Res.* **2005**, *340*, 1287–1300.
8. Andersson, K. N.; Blomberg, E.; Somfai, P. *J. Org. Chem.* **2004**, *69*, 3746–3752.
9. Behrens, C. H.; Sharpless, K. B. *Aldrichim. Acta* **1983**, *16*, 67–79.
10. Katsuki, T.; Lee, A. W. M.; Ma, P.; Martin, V. S.; Masamune, S.; Sharpless, K. B.; Tuddenham, D.; Walker, F. J. *J. Org. Chem.* **1982**, *47*, 1373–1378.
11. (a) Lindström, U. M.; Somfai, P. *Tetrahedron Lett.* **1998**, *39*, 7173–7176; (b) Somfai, P.; Marchand, P.; Torsell, S.; Lindström, U. M. *Tetrahedron* **2003**, *59*, 1293–1299.
12. Reddy, L. V. R.; Sagar, R.; Shaw, A. K. *Tetrahedron Lett.* **2006**, *47*, 1753–1756.
13. (a) Lee, A. W. M.; Martin, V. S.; Masamune, S.; Sharpless, K. B.; Walker, F. J. *J. Am. Chem. Soc.* **1982**, *104*, 3515–3516; (b) *Organic reactions*; Leo A, Paquette et al., Eds.; John Wiley & Sons, 1996; Vol. 48, pp 1–45.
14. Saotome, C.; Kanie, Y.; Kanie, O.; Wong, C.-H. *Bioorg. Med. Chem.* **2000**, *8*, 2249–2261.
15. (a) Camp, F.; Coll, J.; Messeguer, A.; Pericas, M. A. *Tetrahedron Lett.* **1981**, *22*, 3895–3896; (b) Camp, F.; Coll, J.; Messeguer, A.; Pujol, F. *J. Org. Chem.* **1982**, *47*, 5402–5404.
16. Germal, A. L.; Luche, J. L. *J. Am. Chem. Soc.* **1981**, *103*, 5454–5459.
17. (a) Medina, E.; V-Ferran, A.; Moyano, A.; Pericás, M. A.; Riera, A. *Tetrahedron: Asymmetry* **1997**, *8*, 1581–1586; (b) Alcón, M.; Poch, M.; Moyano, A.; Pericás, M. A.; Riera, A. *Tetrahedron: Asymmetry* **1997**, *8*, 2967–2974; (c) Alcón, M.;

Moyano, A.; Pericás, M. A.; Riera, A. *Tetrahedron: Asymmetry* **1999**, *10*, 4639–4651; (d) Fuwa, H.; Okamura, Y.; Natsugari, H. *Tetrahedron* **2004**, *60*, 5341–5352.
18. Ko, S. Y.; Lee, A. W. M.; Masamune, S.; Reed, L. A., III; Sharpless, K. B.; Walker, F. J. *Science* **1983**, *220*, 949–951.
19. Zervas, L. *Ber.* **1930**, *63*, 1689–1690.
20. Richtmyer, N. K.; Carr, C. J.; Hudson, C. S. *J. Am. Chem. Soc.* **1943**, *65*, 1477–1478.
21. Fisher, E.; Tiemann, F. *Ber.* **1894**, *27*, 138–147.
22. Sugihara, J. M.; Schmidt, D. L. *J. Org. Chem.* **1961**, *26*, 4612–4615.
23. (a) Ness, R. K.; Fletcher, H. G.; Hudson, C. S. *J. Am. Chem Soc.* **1950**, *72*, 4547–4549; (b) Zervas, L.; Zioudrou, C. *J. Chem. Soc.* **1956**, 214–215; (c) Kocienski, P.; Pant, C. *Carbohydr. Res.* **1982**, *110*, 330–332.
24. Duclos, A.; Fayet, C.; Gelas, J. *Synthesis* **1994**, 1087–1090.
25. (a) Rolf, D.; Gray, G. R. *J. Am. Chem. Soc.* **1982**, *104*, 3539–3541; (b) Bennek, J. A.; Gray, G. R. *J. Org. Chem.* **1987**, *52*, 892–897.
26. Lundt, I.; Frank, H. *Tetrahedron* **1994**, *50*, 13285–13298.
27. (a) Bock, K.; Pedersen, C.; Thogersen, H. *Acta Chem. Scand. B* **1981**, *35*, 441–449; (b) Wisniewski, K.; Skorupowa, E.; Sokolowski, J. *J. Carbohydr. Chem.* **1991**, *10*, 77–90.
28. (a) Wiggins, L. F. *Adv. Carbohydr. Chem.* **1950**, *5*, 191; (b) Solzberg, S. *Adv. Carbohydr. Chem.* **1970**, *25*, 229; (c) Jaquet, J.; Gaset, A.; Gorrichon, J. P. *Informations* **1984**, *246*, 155.
29. Bellucci, G.; Catelani, G.; Chiappe, C.; D' Andrea, F. *Tetrahedron Lett.* **1994**, *35*, 8433–8436.
30. The diastereomeric ratio was calculated by comparing the proton integration of H-2 in the ^{1}H NMR spectra of the diacetate derivative of the mixture of **15** or **17**.
31. (a) Morimoto, Y.; Iwai, T.; Nishikawa, Y.; Kinoshita, K. *Tetrahedron: Asymmetry* **2002**, *13*, 2641–2647; (b) Pilli, R. A.; Riatto, V. B. *Tetrahedron: Asymmetry* **2000**, *11*, 3675–3686; (c) Yoda, H.; Nakaseko, Y.; Takabe, K. *Tetrahedron Lett.* **2004**, *45*, 4217–4220, and references cited therein.