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STUDIES TOWARD THE TOTAL SYNTHESIS OF CARBA ANALOGUE OF MOTIF C OF *M. TB* CELL WALL AG COMPLEX

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Abstract– Herein we describe the synthesis of the carba analogue of motif C of arabinogalactan complex present in *M. tuberculosis* cell wall. Pd(0) catalyzed allylic alkylation and Fraser-Reid's glycosidation are the two key reactions that were employed for the synthesis of central glycosyl accepter unit and the glycosylation respectively.

The mycolic arabinogalactan (AG) complex present on the surface of the cell wall of *Mycobacterium tuberculosis* has unique structural features unknown in actinomycetes. The furanoside rings of AG complex are conformationally more mobile than the pyranosides and are largely linked through primary hydroxyl groups. These characteristics enable the crowded AG complex to adopt a structure in which mycolic acids are closely arranged in parallel arrays.[1] The AG complex is critical for the survival of *M. tuberculosis*. The hydrophobic AG complex acts as a strong barrier for the passage of antibiotics into the cell and therefore, plays an important role in developing resistance of mycobacteria to many antibiotics. The drug ethambutol blocks the biosynthetic pathway of arabinose. The inhibition of biosynthetic pathway, involved in displacement of *M. tuberculosis* cells, is considered as an attractive strategy for drug discovery and development against *M. tuberculosis*. The structures of the oligosaccharides present on various motifs of AG complex have been elucidated and their synthesis has dominated the area in recent times.

There has been increasing interest in the synthesis of "glycoconjugates" containing carbasugar residues for use as potential therapeutic agents. It is believed that such species will be more efficacious than their glycoside counterparts due to increased acidic and metabolic stability. The approach has already been

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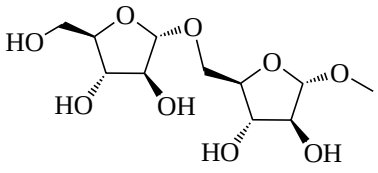
This paper is dedicated to Professor Emeritus Keiichiro Fukumoto on the occasion of his 75th birthday.

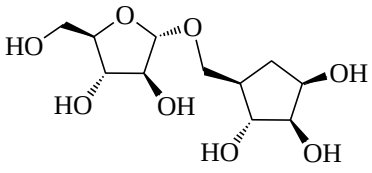
validated by many carbasugar-containing nucleoside analogues possessing demonstrated antiviral activity.[2] Oligosaccharide analogues containing carbasugar residues have been shown to be competent glycosyltranferases: we postulated that arabinosyltransferase inhibitors containing carbasugar residues would manifest similar action and constitute attractive synthetic targets.[3]

The logical extension of this effort was to design a synthetic strategy to assemble carba analogue of disaccharide of motif C. The synthetic target of interest is 5-*O*-(4a-carba-β-D-arabinofuranosyl)-α-D-arabinofuranoside (**2**) as shown in Figure 1.

Figure 1. Motif C of *M. tuberculosis* and its carba analogue



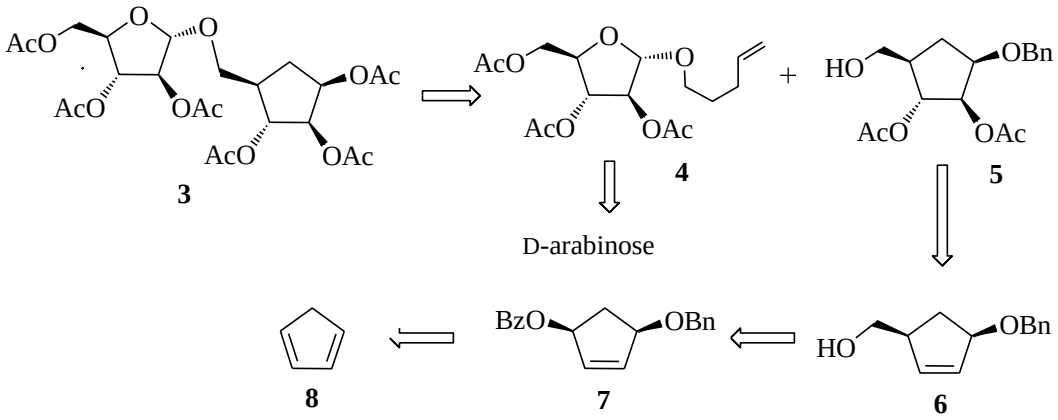
Motif C
1



5-O-(4a-carba-β-D-arabinofuranosyl)-α-D-arabinofuranoside
2

As depicted in the retrosynthetic plan (Scheme 1), the acylated disaccharide **3** can be obtained by *O*-glycosidation between glycosyl donor **4** and glycosyl acceptor **5** with Fraser Reid glycosidation protocol. The pentenyl glycoside donor **4** could be derived from D-arabinose. The carba sugar[4] derivative **5** can be elaborated from **6** through *m*-CPBA epoxidation followed by acid catalysed regioselective epoxide opening.

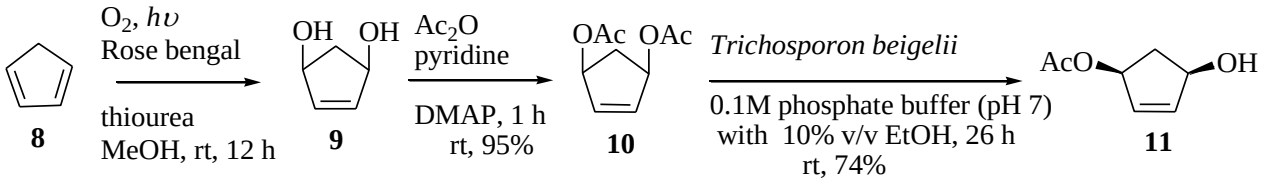
Scheme 1. Retrosynthetic plan



The synthesis of homoallylic alcohol **6** was planned from **7** using a Pd(0) mediated allylic alkylation with phenylsulfonylnitromethane. Cyclopentadiene **8** was chosen as starting point for the synthesis of **7** through enzymatic desymmetrization and protecting group manipulations.

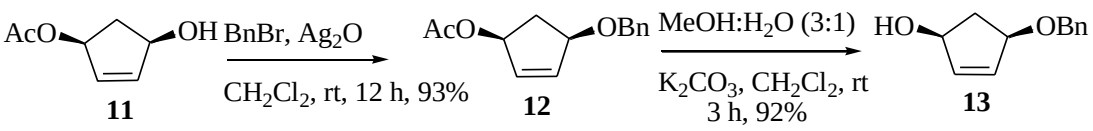
The synthetic sequence started with cyclopentadiene (**8**) to obtain the known *cis*-2-cyclopentene-1,4-diol (**9**) as reported by Kaneko *et al*.[5] Cyclopentadiene (**8**) was treated with molecular oxygen in the presence of thiourea and Rose Bengal in methanol and irradiated with a 450 W high pressure mercury immersion lamp to give *cis*-2-cyclopentene-1,4-diol (**9**) in quantitative yield. Diol **9** was acetylated with acetic anhydride in pyridine using a catalytic amount of DMAP to give *cis*-2-cyclopentene-1,4-diacetate (**10**). The *meso*-di-acetate **10** was enzymatically hydrolysed with *Trichosporone beigelii* (NCIM 3326) in 0.1M sodium phosphate buffer (pH 7) with 10% v/v ethanol to give 4-*R*-hydroxycyclopent-2-en-1-*S*-acetate (**11**) optical purity > 98% (Scheme 2).[6]

Scheme 2. Enzymatic hydrolysis of *meso*-diacetate



We then proceeded towards the synthesis of glycosyl acceptor **5**. The hydroxyl acetate **11** was treated with BnBr and Ag_2O in dry CH_2Cl_2 to afford benzylic derivative **12** (Scheme 3). The ^1H NMR and ^{13}C NMR spectra were in full agreement with the assigned structure. In ^1H NMR spectrum the benzylic protons were observed at δ 4.52-4.59 as two doublets and in ^{13}C NMR the carbonyl carbon was observed at δ 170.5. The benzylic derivative **12** was subjected to deacetylation by using K_2CO_3 in methanol–H_2O (3:1) to furnish **13**. In the ^1H NMR spectrum of **13**, the olefinic protons were observed at δ 6.02 and in the ^{13}C NMR spectrum, the benzylic carbon resonated at δ 70.8.

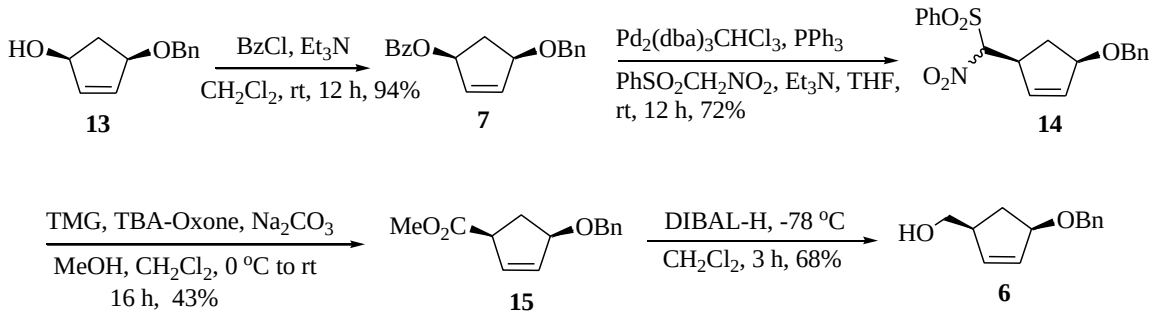
Scheme 3



The free hydroxyl group in **13** was protected as its benzoate by using benzoyl chloride in the presence of Et_3N in CH_2Cl_2 to afford **7** in 94% yield (Scheme 4). The introduction of hydroxymethyl functionality at the benzoate position was accomplished in a highly stereospecific manner through palladium (0) catalyzed allylic alkylation.[7] Thus, the benzoate **7** was subjected to a palladium (0) catalyzed cross-coupling reaction with a phenylsulfonylnitromethane anion to afford **14** as a 1:1 diastereomeric mixture almost quantitatively. The NMR analysis and other analytical data were in full agreement with

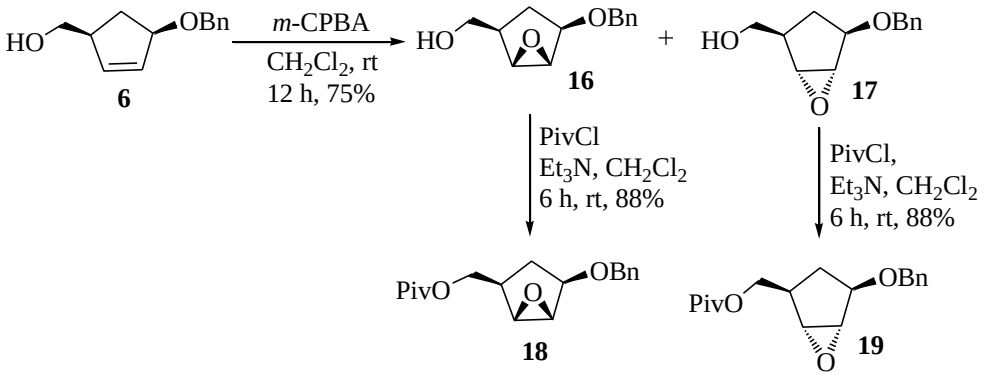
the assigned structure. Further, in the IR spectrum of compound **14**, the characteristic absorption for NO_2 group was observed at 1560 and 1345 cm^{-1}. Treatment of **14** with tetramethylguanidine salt and tetrabutylammonium oxone (TBA-Oxone)[8] in methanol/CH_2Cl_2 buffered with sodium carbonate gave the methyl ester **15** in 43% yield. The methyl ester **15** was treated with DIBAL-H in CH_2Cl_2 at –78 °C to procure the hydroxymethyl derivative **6** in 68% yield. In the ^1H NMR spectrum, the methyl ester peak disappeared and two methylene protons were observed at δ 3.62 as a doublet. Moreover, the ^{13}C NMR spectrum revealed the absence of carbonyl peak and a triplet carbon at δ 65.0.

Scheme 4



Having synthesized the hydroxymethyl derivative **6**, our next objective was to introduce the *trans* diol originating from the ring olefin of **6**. Towards this goal, treatment of **6** with *m*-CPBA gave a diastereomeric mixture of epoxides (β-and α-epoxides) in 7:3 ratio, which were separated by silica gel column chromatography (Scheme 5).

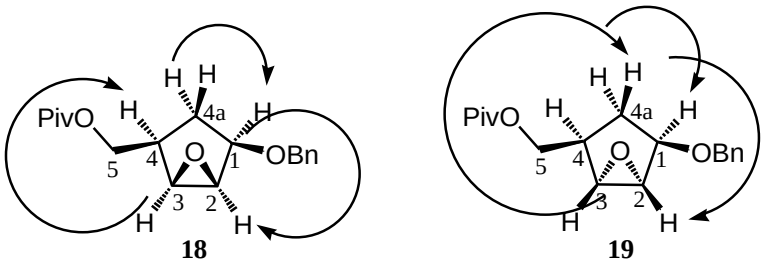
Scheme 5. Synthesis of epoxides



In ^1H NMR spectrum of **16** the epoxide protons were observed as a doublet at δ 3.49; the same resonance for **17** was observed at δ 3.53 as a singlet. To determine the relative configuration of epoxides **16** and **17**,

both the epoxides were independently treated with PivCl and Et_3N in CH_2Cl_2 to furnish the corresponding pivaloate ester derivatives **18** and **19**. Further, COSY/NOESY experiments were carried out on epoxides **18** and **19** and the relative stereochemistry was assigned based on observed spatial interactions (Figure 2).

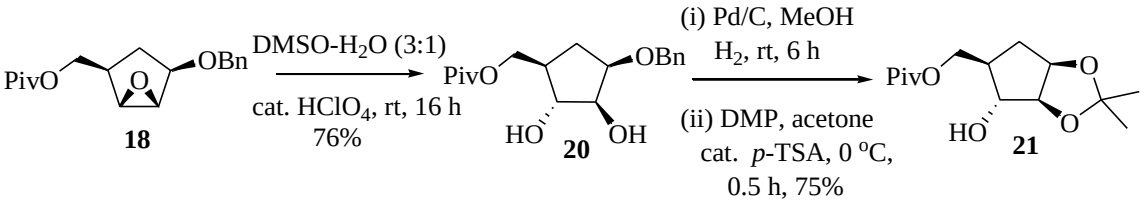
Figure 2. NOESY correlations



In the NOESY spectrum of **18**, the observed spatial interactions between H-C(1) and H-C(2), H-C(1) and H_α-C(4a), H-C(3) and H-C(4) established the assigned structure. Along similar lines, the observed correlations for **19**, i e. H-C(1) and H_α-C(4a), H-C(2) and H_β-C(4a), H-C(3) and H_β-C(4a) supported the assigned structure.

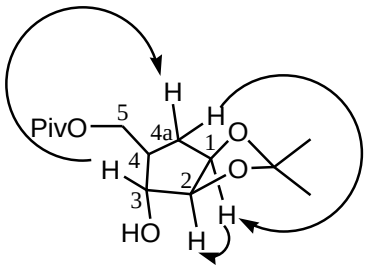
We proceeded with β-epoxide **18** for regioselective epoxide opening.[9] Epoxide **18** was treated with catalytic amount of $HClO_4$ in DMSO-H_2O (3:1) solvent mixture to afford the diol **20** quantitatively. The structure of **20** was fully confirmed by ^1H and ^{13}C NMR spectral analysis. Further, the IR spectrum of **20** revealed the presence of –OH group with absorption at 3432 cm^{-1}. To confirm whether the epoxide opening took place at C2 or C3 position, **20** was subjected to debenzylation using Pd/C (catalytic amount) in methanol under H_2 pressure to give intermediate triol (Scheme 6). The *syn*-diol functionality of triol was protected as its acetonide using 2,2-dimethoxypropane in acetone with catalytic amount of *p*-TSA to give acetonide **21**. In the ^1H NMR spectrum, the two isopropylidene methyl groups were observed at δ 1.29 and 1.48 as two distinct singlets. Further, in ^{13}C NMR spectrum, the quaternary isopropylidene carbon was observed at δ 111.8. Rest of the spectral and analytical data are supportive of the assigned structure.

Scheme 6



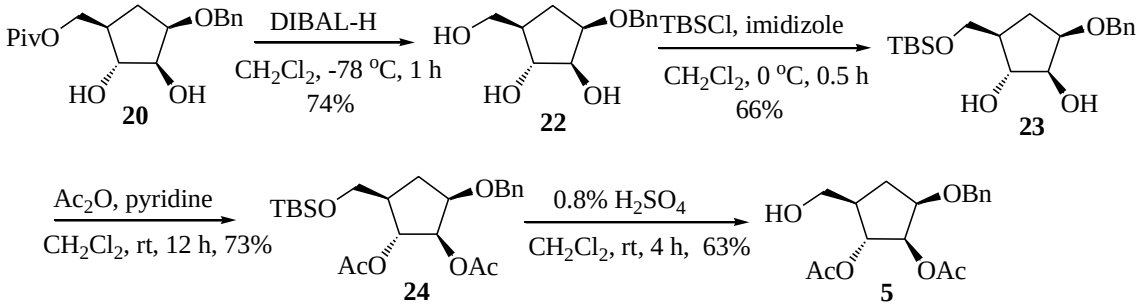
The stereochemistry of **21** was unambiguously confirmed by its COSY/NOESY spectral analysis (Figure 3). The observed spatial interaction between H-C(1) and H-C(2), H-C(1) and H_α-C(4a), H_β-C(3) and H_β-C(4a) confirmed the assigned structure of **21**. Rest of the correlations are in accordance with the given structure of **21** also unambiguously confirms the stereochemistry of epoxide **18**.

Figure 3. NOESY correlations for **21**



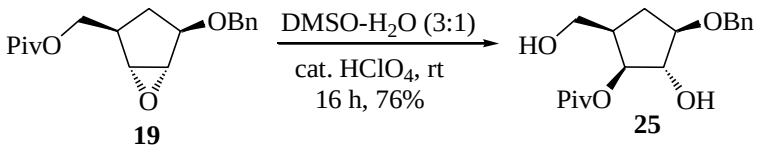
The pivaloate **20** was subjected to DIBAL-H reduction in CH_2Cl_2 at -78 ^oC to give triol **22** in 74% yield. Further, in the IR spectra the characteristic –OH stretch was observed at 3369 cm^{-1}. Primary hydroxyl functionality of triol **22** was protected as its TBS ether using TBS-Cl and imidazole in CH_2Cl_2 to obtain diol **23** quantitatively (Scheme 7). The diol **23** was acetylated using Ac_2O and pyridine in CH_2Cl_2 to furnish the diacetate **24**. Diacetate **24** was subjected to TBS deprotection using catalytic 0.8% H_2SO_4 to afford the glycosyl acceptor **5** in 63% yield. Spectral and analytical data for **5** are supportive of the assigned structure.

Scheme 7. Preparation of glycosyl acceptor



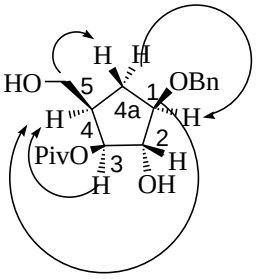
Similarly, the α-epoxide **19** was opened under the same reaction conditions as described for epoxide **18**. Surprisingly, it gave the epoxide opened product with pivaloyl group migration from primary to secondary hydroxyl group. This was confirmed by extensive spectral studies of **25** (Scheme 8).

Scheme 8



COSY/NOESY experiments were performed on diol **25** and the observed correlations were shown in Figure 4.

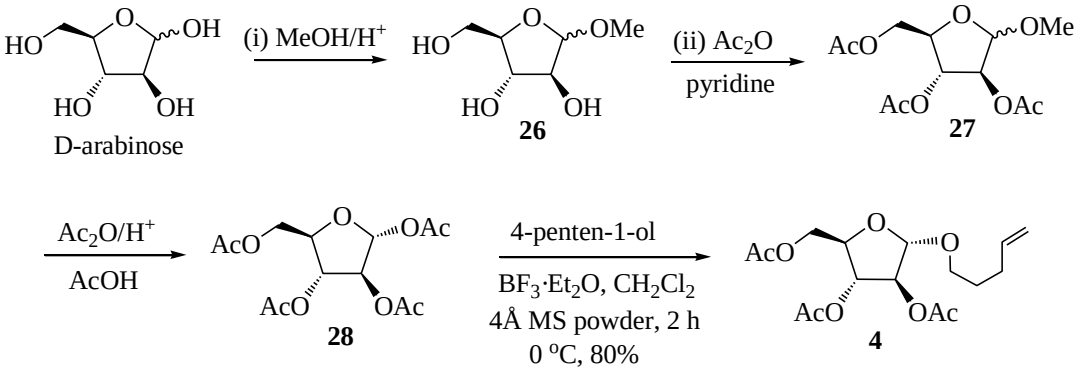
Figure 4. NOESY correlations for **25**



The observed spatial interactions between H-C(1) and H-C(4), H-C(1) and H_{α}-C(4a), H-C(3) and H-C(4), H_{β}-C(4a) and H-C(5) confirmed the assigned structure of **25**. Rest of the correlations are in complete accord with the structure**,** which unambiguously confirms the stereochemistry of epoxide **25**.

Our next endeavor was to synthesize the *n*-pentenyl glycosyl donor **4** starting from D-arabinose. Methyl D-arabinofuranoside (**26**) was prepared from D-arabinose and methanolic HCl at rt, which was subsequently treated with Ac_2O, pyridine to afford methyl 2,3,5-tri-*O*-acetyl-D-arabinofuranoside (**27**). The per-*O*-acetyl-D-arabinose (**28**) was prepared from **27** with $Ac_2O/AcOH/H_2SO_4$ in quantitative yield. Treatment of **28** with 4-penten-1-ol with a catalytic amount of $BF_3{\cdot}OEt_2$ and 4Å MS powder in CH_2Cl_2 at rt furnished pentenyl glycosyl donor **4** (Scheme 9).

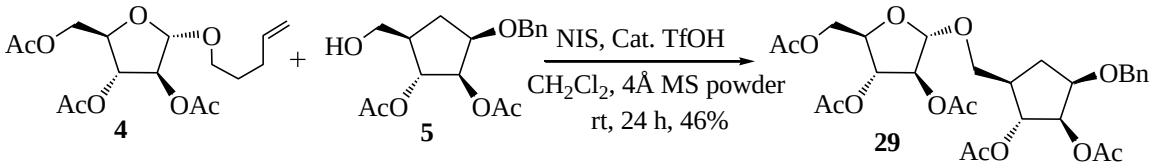
Scheme 9. Preparation of glycosyl donor



With both glycosyl donor (**4**) and glycosyl acceptor (**5**) in hand, we planned for the crucial *O*-glycosylation. as per *n*-pentenyl mediated *O*-glycosylation first disclosed by Fraser-Reid.[10]

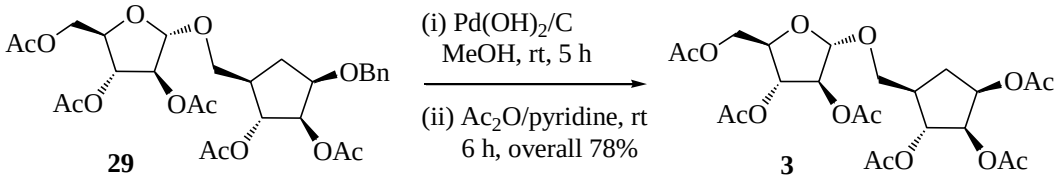
The Fraser-Reid glycosidation reaction between glycosyl donor **4** and glycosyl acceptor **5** in the presence of NIS, TfOH (catalytic) and 4Å MS powder in CH_2Cl_2 at rt gave the disaccharide **29** in 46% yield (Scheme 10).

Scheme 10 . Glycosidation reaction



The 1,2-*trans* configuration of disaccharide of **29** was evident from its ^{1}H and ^{13}C NMR spectra studies. In the ^{1}H NMR spectrum of **29**, the anomeric proton was observed at δ 5.01 as a characteristic singlet. Further, the location of the signal due to C-1' at 105.3 ppm in the ^{13}C NMR spectrum confirmed the α-linkage at the newly formed glycosidic bond and satisfactory elemental analysis supported the structure of **29**. Finally the disaccharide **29** was subjected to debenzylation, under hydrogen, using $Pd(OH)_2$/C in MeOH at rt to give the alcohol which was subsequently acetylated using Ac_2O and pyridine to give hexa-acetyl disaccharide **3** in 78% overall yield (Scheme 11).

Scheme 11



The structure of **3** was unequivocally confirmed by its spectral and analytical data. In the ^{1}H NMR spectrum, the anomeric proton was observed at δ 4.94 as a singlet and rest of the spectrum was in full accordance with the structure. In the ^{13}C NMR spectrum the characteristic C-1 carbon resonated at δ 105.23. The six carbonyl carbons were observed at δ 169.6, 170.0, 170.0, 170.2, 170.3, 170.6.

EXPERIMENTAL

^{1}H NMR spectra were recorded on AV-200 MHz, AV-400 MHz, and DRX-500 MHz spectrometer using tetramethylsilane (TMS) as an internal standard. Chemical shifts have been expressed in ppm units

downfield from TMS ^{13}C NMR spectra were recorded on AV-50 MHz, AV-100 MHz, and DRX-125 MHz spectrometer. EI Mass spectra were recorded on Finnegan MAT-1020 spectrometer at 70 *eV* using a direct inlet system. X-Ray Crystal data were collected on *Bruker SMART APEX* CCD diffractometer using MoK_α radiation with fine focus tube with 50 kV and 30 mA.Infrared spectra were scanned on Shimadzu IR 470 and Perkin-Elmer 683 or 1310 spectrometers with sodium chloride optics and are measured in cm^{-1}.Optical rotations were measured with a JASCO DIP 370 digital polarimeter. All reactions are monitored by Thin Layer chromatography (TLC) carried out on 0.25 mm E-Merck silica gel plates (60F-254) with UV light, I_2, and anisaldehyde in ethanol as developing agents.

(1*S*,4*R*)-4-(Benzyloxy)cyclopent-2-enyl acetate (12).

To a solution of **11** $[\alpha]_D$ –69.3 (*c* 1, $CHCl_3$) and ee > 99% (6 g, 45.3 mmol) in CH_2Cl_2 (720 mL) were added silver oxide (29.4 g, 126.8 mmol) and benzyl bromide (10.8 g, 63.4 mmol) and the reaction mixture was stirred at rt for 12 h. The mixture was filtered through a Celite bed. The filtrate was dried over Na_2SO_4, concentrated and the crude was purified by column chromatography (10% EtOAc in petroleum ether) to yield **12** (9.2 g, 93%) as colorless oil. $[\alpha]_D$ –12.7 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): 3064, 2860, 1735, 1454, 1364, 1240, 1026, 909, 738, 698, 608 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 1.75 (dt, *J* = 4.6, 14.2 Hz, 1H), 2.05 (s, 3H), 2.76 (dt, *J* = 7.3, 14.7 Hz, 1H), 4.48-4.50 (m, 1H), 4.55 (qt, *J* = 11.7 Hz, *J* = 22.0 Hz, 2H), 5.48–5.50 (m, 1H), 5.98–5.99 (m, 1H), 6.11–6.12 (m, 1H), 7.25–7.33 (m, 5H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ: 21.1 (q), 37.5 (t), 70.9 (t), 76.8 (d), 81.1 (d), 127.5 (d), 127.6 (d), 128.3 (d), 132.8 (d), 136.1 (d), 138.2 (s), 170.6 (s). *Anal. Calcd* for $C_{14}H_{16}O_3$: C, 72.39; H, 6.94. Found: C, 72.25; H, 7.20.

(1*S*,4*R*)-4-(Benzyloxy)cyclopent-2-enol (13).

A suspension of **12** (4.0 g, 17.2 mmol), K_2CO_3 (3.65 g, 34.5 mmol) in MeOH:H_2O (50 mL, 3:1) was stirred at rt for 3 h. The mixture was concentrated and extracted with CH_2Cl_2 (60 mL). The aqueous layer was back extracted with CH_2Cl_2 (100 mL). The combined organic extracts were dried over Na_2SO_4, filtered and concentrated. The crude product was purified by column chromatography (20% EtOAc in petroleum ether) to give **13** (3 g, 92%) as colorless oil. $[\alpha]_D$ +21.9 (*c* 1.0, $CHCl_3$): IR ($CHCl_3$): 3387, 2862, 1454, 1359, 1072, 750, 698 cm^{-1}. ^1H NMR ($CDCl_3$, 200 MHz) δ: 1.65 (dt, *J* = 3.9, 14.1 Hz, 1H), 2.23 (br s, 1H), 2.64 (dt, *J* = 7.1, 14.2 Hz, 1H), 4.39–4.64 (m, 4H), 6.02 (s, 2H), 7.25–7.35 (m, 5H). ^{13}C NMR ($CDCl_3$, 50 MHz) δ: 40.6 (t), 70.9 (t), 74.4 (d), 81.5 (d), 127.5 (d), 127.7 (d), 128.3 (d), 133.4 (d), 137.3 (d), 138.0 (s). *Anal. Calcd* for $C_{12}H_{14}O_2$: C, 75.76; H, 7.42. Found: C, 75.74; H, 7.39.

(1*S*,4*R*)-4-(Benzyloxy)cyclopent-2-enyl benzoate (7).

To a solution of **13** (5 g, 26.3 mmol) in CH_2Cl_2 (100 mL) were added triethylamine (5.3 g, 52.6 mmol)

was added benzoyl chloride (5.5 g, 39.5 mmol) slowly. The reaction mixture was stirred at rt for 12 h. The mixture was extracted with CH_2Cl_2 (100 mL), dried over Na_2SO_4, filtered and concentrated. The crude was purified by column chromatography (10% EtOAc in petroleum ether) to produce **7** (7.2 g, 94%) as colorless oil. $[\alpha]_D$ –45.5 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): 3019, 1713, 1274, 1215, 756, 668 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 1.91 (dt, *J* = 4.3, 14.2 Hz, 1H), 2.9 (dt, *J* = 7.3, 14.2 Hz, 1H), 4.55–4.62(m, 3H), 5.75–5.77 (m, 1H), 6.10–6.18 (m, 2H), 7.26-7.35(m, 4H), 7.42 (t, *J* = 7.3 Hz, 2H), 7.53 (q, *J* = 7.3, 13.7 Hz, 2H), 8.04 (d, *J* = 7.3 Hz), 4.55–4.62 (m, 3H), 5.75-5.77 (m, 1H), 6.10–6.18(m, 2H) 7.26-7.35(m, 4H), 7.42 (t, *J* = 7.3 Hz, 2H), 7.53 (q, *J* = 7.3, 13.7 Hz, 2H), 8.04 (d, *J* = 7.3 Hz, 2H). *Anal. Calcd* for $C_{19}H_{18}O_3$: C, 77.53; H, 6.16. Found: C, 77.48; H, 6.57.

(((1*S*,4*R*)-4-(Benzyloxy)cyclopent-2-enyl)(nitro)methylsulfonyl)benzene (14).

To a deoxygenated solution of triphenylphosphine (89 mg, 0.34 mmol) in THF (20 mL) was added $Pd_2(dba)_3{\cdot}CHCl_3$ (35 mg, 0.034 mmol). The mixture was stirred for 20 min. It was then added to a deoxygenated solution of monobenzoate **7** (1 g, 3.4 mmol), phenylsulfonylnitromethane (821 mg, 4.1 mmol) and triethylamine (860 mg, 8.5 mmol) in THF (20 mL). After stirring for 12 h the reaction mixture was diluted with $CHCl_2$ (25 mL) and washed with water (100 mL). The aqueous phase was extracted with $CHCl_2$ (250 mL), and the combined organic layers were dried over Na_2SO_4 and concentrated. The residue was purified by column chromatography (6% EtOAc in petroleum ether) to give **14** (0.9 g, 72%) as 1:1 diastereomeric mixture. IR ($CHCl_3$): 3030, 2864, 1560, 1449, 1345, 1082, 755, 686 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 1.62 (dt, *J* = 4.1, 13.7 Hz, 1H), 2.27 (dt, *J* = 3.6, 14.2 Hz, 1H), 2.36 (dt, *J* = 6.8, 14.2 Hz, 1H), 2.50 (dt, *J* = 7.3, 14.6 Hz, 1H), 3.50-3.61 (m, 2H), 4.45-4.53 (m, 4H), 4.57-4.60 (m, 2H), 5.47 (qt, *J* = 10.5, 16.9 Hz, 2H), 5.63-5.64 (m, 1H), 6.13-6.16 (m, 2H), 6.30-6.31 (m, 1H), 7.26–7.36 (m, 9H), 7.60 (t, *J* = 7.5, 4H), 7.75 (t, *J* = 7.3 Hz, 2H), 7.89-7.91 (m, 4H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ: 33.6 (d), 34.6 (d), 43.2 (d), 43.51 (d), 71.38 (d), 81.5 (d), 82.8 (d), 96.2 (d), 105.3 (s), 105.6 (s), 127.8 (d), 128.4 (d), 129.4 (d), 129.96 (d), 129.99 (d), 131.6 (d), 131.9 (d),135.3 (s), 135.9 (s), 137.06 (s). *Anal. Calcd* for $C_{19}H_{19}NO_5S$: C, 61.11; H, 5.13; N, 3.75; S, 8.59. Found: C, 61.14; H, 5.09; N, 3.71; S, 8.60.

(1*S*,4*R*)-Methyl 4-(benzyloxy)cyclopent-2-enecarboxylate (15).

To an ice cold solution of nitrosulfone **14** (2.0 g, 5.36 mmol) in MeOH (40 mL) was added tetramethylguanidine (0.93 g, 8.1 mmol) and the mixture was stirred at 0 ^oC for 15 min. This was followed by addition of TBA-Oxone (22.98 g, 26.8 mmol), Na_2CO_3 (2.84 g, 26.8 mmol) and CH_2Cl_2 (50 mL). The solution was stirred at rt for 16 h. It was then diluted with $CHCl_3$ and washed with water (100 mL). The aqueous layer was extracted with $CHCl_3$ (200 mL), and the combined $CHCl_3$ layers were dried over Na_2SO_4, and concentrated. The residue was purified by column chromatography (6% EtOAc in

petroleum ether) to give **15** (0.53 g, 43%) as colourless oil. $[\alpha]_D$ –46.8 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): 3019, 2863, 1733, 1360, 1216, 1068, 756, 667 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 2.13 (dt, *J* = 6.4, 13.7 Hz, 1H), 2.51 (dt, *J* = 8.7, 13.7 Hz, 1H), 3.43-3.46 (m, 1H), 3.71 (s, 3H), 4.52 (d, *J* = 11.9 Hz, 1H), 4.57 (d, *J* = 11.9 Hz, 1H), 4.64 (t, *J* = 6.4 Hz, 1H), 5.96-5.99 (m, 2H), 7.24-7.34 (m, 5H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ: 33.3 (t), 48.9 (q), 51.9 (d), 70.8 (t), 83.3 (d), 127.5 (d), 127.8 (d), 128.4 (d), 132.0 (d), 133.9 (d), 138.7 (s), 173.5 (s). *Anal. Calcd* for $C_{14}H_{16}O_3$: C, 72.39; H, 6.94. Found: C, 72.34; H, 6.92.

((1*S*,4*R*)-4-(Benzyloxy)cyclopent-2-enyl)methanol (6).

At –78 °C a solution of ester **15** (1.0 g, 4.31 mmol) in CH_2Cl_2 (20 mL) was treated with DIBAL-H (1.53 g, 10.77 mmol) –78 °C for 1 h and quenched with saturated solution of sodium potassium tartarate (2 mL) at the same temperature. The mixture was warmed to rt and stirred for 3 h. The organic phase was separated and the aqueous phase was extracted with CH_2Cl_2. The combined extracts were dried over Na_2SO_4 and concentrated. The crude product was purified by column chromatography (15% EtOAc in petroleum ether) to yield **6** (0.6 g, 68%) as colourless oil. $[\alpha]_D$ +21.9 (*c* 1, $CHCl_3$). IR ($CHCl_3$): 3400, 2865, 1364, 1091, 1043, 736, 697 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 1.57 (br s, 1H), 1.68 (dt, *J* = 3.2, 13.7 Hz, 1H), 2.28 (dt, *J* = 7.3, 14.2 Hz, 1H), 2.86 (br s, 1H), 3.62 (d, *J* = 4.6 Hz, 2H), 4.52-4.58 (m, 3H), 5.95-6.02 (m, 2H), 7.24-7.32 (m, 5H).^{13}C NMR ($CDCl_3$, 125 MHz) δ: 33.9 (t), 46.8 (d), 65.0 (t), 70.9 (t), 82.9 (d), 127.6 (d), 127.7 (d), 128.4 (d), 132.6 (d), 136.8 (d), 138.4 (s). *Anal. Calcd* for $C_{13}H_{16}O_2$: C, 76.44; H, 7.90. Found: C, 75.47; H, 7.84.

((1*S*,2*R*,4*R*,5*R*)-4-(Benzyloxy)-6-oxabicyclo[3.1.0]hexan-2-yl)methanol (16).

Epoxidation of cyclopentene 6.

To a solution of **6** (1 g, 4.9 mmol) in CH_2Cl_2 (16 mL), was added *m*-CPBA (2.11 g, 12.25 mmol) at 0 °C and the mixture was stirred at rt for 12 h. Precipitated *m*-chloroperbenzoic acid was filtered. The filtrate was concentrated and the residue was purified by column chromatography (40% EtOAc in petroleum ether) to obtain **16** (570 mg, 52.5%) and **17** (240 g, 22.5%) as colorless liquids. $[\alpha]_D$ –10.1 (*c* 1.2, $CHCl_3$). IR ($CHCl_3$): 3412, 3019, 1716, 1215, 757, 669 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 1.17-1.23 (m, 1H), 1.86-1.91 (m, 1H), 2.11-2.16 (m, 1H), 3.49 (d, *J* = 15.6 Hz, 2H), 3.75 (d, *J* = 6.4, 2H), 4.05 (t, *J* = 7.8 Hz, 1H), 4.61 (dt, *J* = 12.4, 16.0 Hz, 2H), 7.27-7.36 (m, 5H).^{13}C NMR ($CDCl_3$, 125 MHz) δ: 26.5 (t), 40.2 (d), 55.8 (d), 56.5 (d), 62.8 (t), 71.6 (t), 78.8 (d), 127.7 (d), 128.4 (d), 138.0 (s). *Anal. Calcd* for $C_{13}H_{16}O_3$: C, 70.89; H, 7.32. Found: C, 70.87; H, 7.29.

((1*S*,2*R*,4*R*,5*R*)-4-(Benzyloxy)-6-oxabicyclo[3.1.0]hexan-2-yl)methanol (17).

$[\alpha]_D$ –16.3 (*c* 1, $CHCl_3$). IR ($CHCl_3$): 3426, 3032, 2973, 2873, 1729, 1480, 1153, 840 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 1.57 (d, *J* = 14.8 Hz, 1H), 1.80-1.94 (m, 1H), 2.43-2.51 (m, 1H), 2.90 (br s, 1H),

3.53 (s, 2H), 3.70 (dd, *J* = 4.30, 7.83 Hz, 2H), 4.09 (d, *J* = 5.5 Hz, 1H), 4.61 (d, *J* = 3.1 Hz, 2H), 7.31 (s, 5H). *Anal. Calcd* for $C_{13}H_{16}O_3$: C, 70.89; H, 7.32. Found: C, 70.79; H, 7.12.

((1*S*,2*R*,4*R*,5*R*)-4-(Benzyloxy)-6-oxabicyclo[3.1.0]hexan-2-yl)methyl pivaloate (18).

To a solution of **16** (500 mg, 2.27 mmol) in CH_2Cl_2 (12 mL) at 0 °C were added pyridine (530 mg, 4.54 mmol) and pivaloyl chloride (550 mg, 4.54 mmol). The reaction mixture was stirred for 6 h and concentrated. The crude product was purified by column chromatography (10% EtOAc in petroleum ether) to yield **18** (640 mg, 88%) as colourless oil. $[\alpha]_D$ –17.9 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): 3028, 2974, 1725, 1480, 1273, 1158, 754, 715 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 1.21 (s, 10H), 1.88 (dt, *J* = 7.3, 12.8 Hz, 1H), 2.20-2.26 (m, 1H), 3.30 (d, *J* = 2.7 Hz, 1H), 3.50 (d, *J* = 2.7 Hz, 1H), 4.03 (t, *J* = 8.5 Hz, 1H), 4.07-4.10 (q, *J* = 8.2 Hz, 1H), 4.17-4.22 (m, 1H), 4.61 (s, 2H), 7.26–7.45 (m, 5H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ: 26.9 (t), 27.2 (q), 37.4 (d), 38.8 (s), 55.2 (d), 56.4 (d), 64.0 (t), 71.6 (t), 78.6 (d), 127.8 (d), 128.4 (d), 138.0 (s), 178.3 (s). *Anal. Calcd* for $C_{18}H_{24}O_4$: C, 71.05; H, 7.89. Found: C, 71.09; H, 7.85.

((1*R*,2*R*,4*R*,5*S*)-4-(Benzyloxy)-6-oxabicyclo[3.1.0]hexan-2-yl)methyl pivalate (19).

To a solution of **17** (500 mg, 2.27 mmol) in CH_2Cl_2 (12 mL) at 0 °C were added pyridine (530 mg, 4.54 mmol) followed by pivaloyl chloride (550 mg, 4.54 mmol). The reaction mixture was stirred at rt for 6 h., concentrated and the crude was purified by column chromatography (10% EtOAc in petroleum ether) to yield **19** (640 mg, 88%) as colourless oil. $[\alpha]_D$ –15.0 (*c* 1, $CHCl_3$). IR ($CHCl_3$): 3032, 2973, 2873, 1729, 1480, 1282, 1153, 1094, 840, 697 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 1.15 (s, 9H), 1.48 (d, *J* = 14.6 Hz, 1H), 1.62-1.68 (m, 1H), 2.50 (q, *J* = 7.8 Hz, 1H), 3.43 (d, *J* = 6.9 Hz, 2H), 3.95-4.03 (m, 2H), 4.05-4.12 (m, 1H), 4.42 (d, *J* = 11.9 Hz, H), 4.51 (d, *J* = 11.5 Hz, 1H), 7.19-7.27 (m, 5H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ: 27.3 (q), 30.1 (t), 38.4 (s), 56.9 (d), 58.5 (d), 64.9 (d), 71.7 (t), 78.3 (d), 127.6 (d), 127.8 (d), 128.5 (d), 128.5 (s), 129.7 (s), 133.3 (s), 138.0 (s), 177.9 (s). *Anal. Calcd* for $C_{18}H_{24}O_4$: C, 71.03; H, 7.95. Found: C, 70.83; H, 7.75.

(1*S*,2*S*,3*R*,5*R*)-3-(Benzyloxy)-2-hydroxy-5-(hydroxymethyl)cyclopentyl pivalate (25).

To a solution of **19** (500 g, 1.54 mmol) in 3:1 of DMSO: H_2O (10 mL) was added a catalytic amount of perchloric acid (70%) at 0 °C. The reaction mixture was stirred at rt for 16 h. The mixture was extracted with EtOAc (3 X 10 mL) and the combined organic layers were dried over Na_2SO_4, filtered and concentrated. The residue was purified by column chromatography (6% EtOAc in petroleum ether) to give **25** (370 mg, 76%) as colorless oil. $[\alpha]_D$ –24.5 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): 3416, 3021, 1740, 1115, 736, 643 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 1.23 (s, 9H), 1.62-1.70 (m, 1H), 2.16 (dt, *J* = 6.9, 13.1 Hz, 1H), 2.38-2.52 (m, 1H), 3.16 (br s, 1H), 3.63-3.66 (m, 2H) 3.81-3.9, (m, 1H), 4.05 (t, *J* = 3.9 Hz, 1H), 4.59 (d, *J* = 5.3 Hz, 2H), 4.77-4.82 (q, *J* = 3.3, 6.7 Hz, 1H), 7.28-7.34 (m, 5H). ^{13}C NMR ($CDCl_3$, 125

MHz) δ: 27.2 (q), 31.9 (t), 41.3 (d), 61.5 (t), 71.7 (t), 76.8 (d), 81.9 (d), 83.0 (d), 83.6 (d), 127.7 (d), 127.8 (d), 128.4 (d), 128.5 (d), 129.8 (s), 138.1 (s), 179.8 (s). *Anal. Calcd* for $C_{18}H_{26}O_5$: C, 67.06; H, 8.13. Found: C, 66.98; H, 8.03.

((1*R*,2*R*,3*S*,4*R*)-4-(Benzyloxy)-2,3-dihydroxycyclopentyl)methyl pivaloate (20).

To a solution of **18** (500 mg, 1.54 mmol) in 3:1 of DMSO: H_2O (10 mL) was added a catalytic amount of perchloric acid (70%) at 0 °C. The reaction mixture was stirred at rt for 16 h. The mixture was extracted with EtOAc (3 X 10 mL) and the combined organic layers were dried over Na_2SO_4, filtered and concentrated. The residue was purified by column chromatography (6% EtOAc in petroleum ether) to give **20** (370 mg, 76%) as colorless oil. $[\alpha]_D$ –35.5 (*c* 0.4, $CHCl_3$). IR ($CHCl_3$): 3432, 3019, 1720, 1215, 757, 668 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 1.13 (s, 9H), 1.45-1.59 (m, 1H), 1.76 (br s, 1H), 1.95-2.15 (m, 2H), 3.77-3.88 (m, 2H), 4.00-4.13 (m, 2H), 4.4 (d, *J* = 11.6 Hz, 1H), 4.56 (d, *J* = 11.6 Hz, 1H), 7.23-7.29 (m, 5H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ: 27.1 (q), 29.8 (t), 38.8 (s), 40.7 (d), 65.5 (t), 71.4 (t), 76.7 (d), 78.4 (d), 78.5 (d), 127.7 (d), 127.9 (d), 128.4 (d), 137.5 (s), 178.6 (s). *Anal. Calcd* for $C_{18}H_{26}O_5$: C, 67.08; H, 8.13. Found: C, 66.89; H, 7.15.

((3a*S*,4*R*,5*R*,6a*R*)-4-Hydroxy-2,2-dimethyltetrahydro-*3aH*-cyclopenta[*d*][1,3]dioxol-5-yl)methyl pivaloate (21).

To a solution of **20** (100 mg) in MeOH (5 mL), was added Pd/C (10%, 50 mg) and stirred at rt under H_2 atmosphere for 6 h. The mixture was filtered through a Celite bed and the filtrate was concentrated. The crude triol was used directly for the next reaction. To a solution of triol (80 mg, 0.34 mmol) in acetone (6 mL), were added dimethoxypropane (530 mg, 0.5 mmol) and a catalytic amount of *p*-TSA (5 mg). The solution was stirred at 0 °C for 0.5 h and quenched with solid $NaHCO_3$ and the neutral reaction mixture was concentrated in *vacuo.* The residue obtained was purified by column chromatography (20% EtOAc in petroleum ether) to obtain **21** (60 mg, 75%) as colorless oil. $[\alpha]_D$ –26.4 (*c* 1, $CHCl_3$). IR ($CHCl_3$**)**: 3435, 1721, 1480, 1215, 928, 758, 669 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 1.22 (s, 9H), 1.29 (s, 3H), 1.48 (s, 3H), 1.63 (br s, 1H), 1.14-1.70 (m, 1H), 2.16-2.24 (m, 2H), 3.96 (dd, *J* = 3.21, 5.04 Hz, 1H), 4.16 (dddd, *J* = 5.5, 11.0, 16.9 Hz, 2H), 4.39 (dd, *J* = 3.2, 6.9 Hz, 1H), 4.67-4.70 (m, 1H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ: 24.4 (q), 26.8 (q), 27.3 (q), 32.5 (t), 46.1 (d), 64.3 (t), 78.5 (d), 78.7 (d), 87.0 (d), 111.77 (d), 178.4 (s), 178.8 (s). *Anal. Calcd* for $C_{14}H_{24}O_5$: C, 61.74 H, 8.88. Found: C, 61.78; H, 8.85.

(1*R*,2*S*,3*R*,5*R*)-3-(Benzyloxy)-5-(hydroxymethyl)cyclopentane-1,2-diol (22).

A solution of **20** (400 mg, 1.24 mmol) in CH_2Cl_2 (15 mL) was cooled to –78 °C. DIBAL-H (440 mg, 3.1 mmol) was added dropwise and the mixture was stirred at –78 °C for 1 h. The reaction was quenched with saturated solution of sodium potassium tartarate (5 mL), warmed to rt and stirred for additional 3 h.

Organic phase was separated and the aqueous phase was extracted with CH_2Cl_2. The combined organic extracts were dried over Na_2SO_4 and concentrated. The crude residue was purified by column chromatography (80% EtOAc in petroleum ether) to afford **22** (220 mg, 74.5%) as a colorless oil. $[\alpha]_D$ –2.9 (*c* 1.0, MeOH). IR ($CHCl_3$): 3369, 2930, 1454, 1046, 753, 698 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 1.44 (br s, 1H), 1.87 (br s, 1H), 1.96-2.03 (m, 1H), 3.53 (t, *J* = 7.3 Hz, 1H), 3.62 (br s, 1H), 3.81 (br s, 2H), 3.82-3.96 (br s, 4H), 4.44 (d, *J* = 11.4 Hz, 1H), 4.53 (d, *J* = 11.4 Hz, 1H), 7.22-7.31 (m, 5H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ: 29.4 (t), 43.4 (d), 65.0 (t), 71.6 (t), 77.5 (d), 78.6(d), 79.2 (d), 127.9 (d), 128.5 (d), 137.9 (s). *Anal. Calcd* for $C_{13}H_{18}O_4$: C, 65.53; H, 7.61. Found: C, 65.37; H, 7.26.

(1*R*,2*S*,3*R*,5*R*)-3-(Benzyloxy)-5-((*tert*-butyldimethylsilyloxy)methyl)cyclopentane-1,2-diol (23).

To an ice-cold solution of **22** (500 mg, 2.1 mmol) in CH_2Cl_2 (12 mL), were added imidazole (420 mg, 6.3 mmol) and TBS-Cl (340 mg, 2.31 mmol). The reaction mixture was stirred for 0.5 h concentrated and purified by column chromatography (40% EtOAc in petroleum ether) to yield **23** (490 mg, 66%) as colorless oil. $[\alpha]_D$ –18.9 (*c* 0.8, $CHCl_3$). IR ($CHCl_3$): 3424, 2929, 1255, 1216, 1067, 837, 758, 668 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 0.06 (d, *J* = 1.9 Hz, 6H), 0.90 (s, 9H), 1.50 (dddd, *J* = 4.4, 8.8, 13.2, 18.1 Hz, 1H), 1.62 (br s, 1H), 1.9 (dt, *J* = 7.8, 16.6 Hz, 1H), 2.6 (dq, *J* = 6.3, 8.8, 15.1Hz, 1H), 2.69–2.71 (d, *J* = 5.8, 1H), 3.60 (t, *J* = 7.83 Hz, 1H), 3.74 (qt, *J* = 5.4, 9.8 Hz, 1H), 3.85 (br s, 1H), 3.89–3.94 (m, 2H), 4.49 (d, *J* = 11.7 Hz, 1H), 4.61 (d, *J* = 11.7 Hz, 1H), 7.30-7.37 (m, 5H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ: 5.4 (q), 18.2 (s), 25.9 (q), 29.4 (t), 43.2 (d), 66.0 (t), 71.4 (t), 77.0 (d), 78.3 (d), 80.5 (d), 127.7 (d), 127.8 (d), 128.5 (d), 137.9 (s). *Anal. Calcd* for $C_{19}H_{32}O_4Si$: C, 64.73; H, 9.15. Found: C, 64.66; H, 9.12.

(1*R*,2*R*,3*R*,5*R*)-3-(Benzyloxy)-5-((*tert*-butyldimethylsilyloxy)methyl)cyclopentane-1,2-diyl diacetate (24).

To a solution of **23** (400 mg, 1.13 mmol) in pyridine (8 mL), was added acetic anhydride (460 mg, 4.54 mmol) at 0 ^oC. The reaction mixture was stirred for 12 h, and concentrated. The residue obtained was purified by column chromatography (10% EtOAc in petroleum ether) to give **24** (340 mg, 73%) as colorless oil. $[\alpha]_D$ –8.6 (*c* 1.7, MeOH). IR ($CHCl_3$): 3019, 2929, 1737, 1216, 1108, 838, 758, 668 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 0.02 (d, *J* = 1.3 Hz, 6H), 0.87 (s, 9H), 1.73-1.81 (m, 1H), 2.02-2.08 (m, 8H), 3.56-3.76 (m, 2H), 3.96-4.05 (m, 1H), 4.50-4.51 (m, 2H), 5.10 (qt, *J* = 4.4, 3.8 Hz, 2H), 7.26-7.34 (m, 5H).^{13}C NMR ($CDCl_3$, 125 MHz) δ: 5.53 (q), 5.44 (q), 18.2 (s), 20.9 (q), 21.02 (q), 25.9 (q), 30.8 (t), 42.9 (d), 64.4 (t), 71.9 (t), 78.0 (d), 127.5 (d), 128.4 (d), 138.2 (s), 170.1 (s), 170.4 (s). *Anal. Calcd* for $C_{23}H_{36}O_6Si$: C, 63.27; H, 8.31. Found: C, 63.54; H, 8.26.

(1*R*,2*R*,3*R*,5*R*)-3-(Benzyloxy)-5-(hydroxymethyl)cyclopentane-1,2-diyl diacetate (5).

To a solution of **24** (300 mg) in EtOH (8 mL), 0.8% H_2SO_4 (catalytic amount) was added stirred at rt for

4 h. The reaction mixture was concentrated and the crude was purified by column chromatography (15% EtOAc in petroleum ether) to obtain **5** (150 mg, 63%) as colorless oil. $[\alpha]_D$ –9.1 (*c* 1.5, MeOH). IR ($CHCl_3$): 3392, 1737, 1373, 908, 733, 650 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 1.62-1.74 (m, 1H), 2.09-2.10 (d, *J* = 1.5 Hz, 6H), 2.14-2.24 (m, 1H), 2.81 (br s, 1H), 3.58-3.71 (m, 2H), 4.04-4.14 (m, 1H), 4.52 (s, 2H), 5.08-5.13 (m, 2H), 7.29-7.38 (m, 5H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ: 20.9 (q), 21.1 (q), 30.9 (t), 43.5 (d), 64.7 (t), 71.93 (t), 76.2 (d), 77.4 (d), 78.7 (d), 127.5 (d), 127.7 (d), 128.4 (d), 137.9 (s), 170.4 (s), 171.7 (s). *Anal. Calcd* for $C_{17}H_{22}O_6$: C, 63.34; H, 6.88. Found: C, 63.23; H, 7.84.

(2*R*,3*R*,4*S*)-2-(Acetoxymethyl)-5-(pent-4-enyloxy)tetrahydrofuran-3,4-diyl diacetate (4).

A solution of per-O-acetyl-D-arabinofuranose (**28**) (1.0 g, 3.14 mmol), 4-penten-1-ol (400 mg, 4.71 mmol), and 4Å MS powder (100 mg) in CH_2Cl_2 (25 mL) under nitrogen was treated with $BF_3{\cdot}Et_2O$ (0.1 mL) at 0 °C. After 2 h, solid $NaHCO_3$ was added and the mixture filtered through Celite. The filtrate was washed with brine, dried (Na_2SO_4) and concentrated. The residual syrup was purified by column chromatography (20% EtOAc in petroleum ether) to obtain **4** (870 mg, 80%) as colorless oil. $[\alpha]_D$ +65.9 (*c* 1, $CHCl_3$). IR ($CHCl_3$): 3024, 2940, 1745, 1371, 1230, 1047, 913, 667 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 1.63-1.78 (m, 3H), 2.11 (s, 10H), 3.46 (qt, *J* = 6.3, 12.5 Hz, 1H), 3.72 (dt, *J* = 6.7, 9.6 Hz, 1H), 4.17-4.28 (m, 2H), 4.39-4.48 (m, 1H), 4.94-5.08 (m, 5H), 5.72-5.92 (m, 1H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ: 20.6 (q), 28.4 (t), 30.0 (t), 63.1 (t), 66.6 (t), 76.9 (d), 80.0 (d), 81.1 (d), 95.9 (s), 105.3 (d), 114.8 (t), 137.8 (d), 169.3 (s), 169.9 (s), 170.3 (s). *Anal. Calcd* for $C_{16}H_{24}O_8$: C, 55.81; H, 7.02. Found: C, 56.79; H, 7.36.

2,3,2',3',5'-*O*-Pentaacetyl-1-*O*-benzyl-5-*O*-(4a-carba-β-D-arabinofuranozyl)-α-D-arabinofuranoside (29).

To a stirred suspension of **4** (160 mg, 0.62 mmol) and **5** (100 mg, 0.31 mmol) and 4Å MS powder in dry CH_2Cl_2 (5 mL), were added NIS (130 mg, 0.62 mmol) and cat. TfOH. The reaction mixture was stirred in the dark at rt for 24 h and filtered through a Celite bed. The filtrate was washed with saturated aqueous solution of $NaHSO_3$ and aqueous $NaHCO_3$ followed by brine solution. The organic layer was dried (Na_2SO_4), concentrated. The crude product was purified by column chromatography (20% EtOAc in petroleum ether) to obtain **29** (40 mg, 45%) as colorless oil. $[\alpha]_D$ +30.9 (*c* 0.8, $CHCl_3$). IR ($CHCl_3$): 3020, 2927, 1742, 1372, 1216, 1083, 758, 669 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 1.77-1.84 (m, 1H), 2.05 (s, 3H), 2.07 (s, 3H), 2.08 (s, 6H), 2.11 (s, 3H), 2.13-2.18 (m, 2H), 3.57 (dd, *J* = 5.0, 9.6 Hz, 1H), 3.73 (dd, *J* = 6.9, 9.6 Hz, 1H), 4.04 (qt, *J* = 5.5, 10.5 Hz, 1H), 4.16-4.24 (m, 3H), 4.38 (dd, *J* = 3.2 Hz, 11.5 Hz, 1H), 4.50 (s, 2H), 4.93 (dd, *J* = 1.4, 4.6 Hz, 1H), 5.01 (s, 1H), 5.04-5.12 (m, 2H), 5.17 (t, *J* = 5.9 Hz, 1H), 7.27-7.34 (m, 5H). ^{13}C NMR ($CDCl_3$, 125 MHz**)** δ: 20.6 (q), 20.7 (q), 20.8 (q), 20.9 (q), 30.9 (t), 40.0 (d), 63.2 (t), 68.2 (t), 71.9 (t), 76.4 (d), 77.11 (d), 77.14 (d), 77.3 (d), 80.4 (d), 81.0 (d), 105.3 (d), 127.5 (d),

127.7 (d), 128.4 (d), 128.6 (d), 138.1 (s), 169.5 (s), 169.9 (s), 170.1 (s), 170.2 (s), 170.4 (s). *Anal. Calcd* for $C_{28}H_{36}O_{13}$: C, 57.93; H, 6.25. Found: C, 59.86; H, 6.22.

1,2,3,2',3',5'-*O*-Hexaacetyl-5-*O*-(4a-carba-β-D-arabinofuranozyl)-α-D-arabinofuranoside (3).

To solution of **29** (40 mg) in EtOAc (3 mL), was added $Pd(OH)_2/C$ (20%, 20 mg) The mixture was stirred for 5 h under hydrogen, filtered through a Celite bed and concentrated. The crude alcohol was directly taken for the next reaction. To a solution of crude alcohol (35 mg, 0.071 mmol) in pyridine (2 mL) was added acetic anhydride (140 mg, 0.14 mmol). The solution was stirred at rt for 6 h. Pyridine and acetic anhydride were removed under reduced pressure. Purification of the crude residue by column chromatography (30% EtOAc in petroleum ether) afforded **3** (25 mg, 78%) as colorless oil. $[\alpha]_D$ +36.6 (*c* 1, $CHCl_3$). IR ($CHCl_3$): 3020, 2927, 2400, 1743, 1371, 1215, 1052, 758, 669, 529 cm^{-1}. ^1H NMR ($CDCl_3$, 500 MHz) δ: 1.76-1.82 (m, 1H), 2.04 (s, 3H), 2.06 (s, 3H), 2.07 (s, 3H), 2.11 (d, *J* = 2.0 Hz, 9H), 2.22-2.39 (m, 2H), 3.55 (dd, *J* = 4.9, 9.5 Hz, 1H), 3.75 (dd, *J* = 6.7, 6.4 Hz, 1H), 4.18-4.29 (m, 2H), 4.39-4.49 (m, 1H), 4.96 (dd, *J* = 1.0, 4.2 Hz, 1H), 5.04 (s, 1H), 5.07 (d, *J* = 1.5 Hz, 1H), 5.12-5.18 (m, 1H), 5.21-5.30 (m, 2H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ: 20.6 (q), 20.76 (q), 20.79 (q), 20.8 (q), 20.9 (q), 30.2 (t), 39.6 (d), 63.3 (t), 67.6 (t), 71.0 (d), 76.18 (d), 76.2 (d), 77.1 (d), 77.2 (d), 80.6 (d), 80.9 (d), 105.2 (d), 169.6 (s), 170.0 (s), 170.1 (s), 170.2 (s), 170.3 (s), 170.6 (s). *Anal. Calcd* for $C_{23}H_{32}O_{14}$: C, 51.87; H, 6.06. Found: C, 51.84; H, 6.10.

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REFERENCES

1. N. D. Connell and H. M. Nikaido, In *Tuberculosis*: *Pathogenesis*, *Protection and Control*, ed. by B. R. Bloom, American Chemical Society for Microbiology, Washington, DC, 1994, p. 333.
2. (a) Xiaolei Tan, Chung K. Chu, and F. Douglas Boudinot, *Adv. Drug Delivery Rev.*, 1999, **39**, 117. (b) T. S. Mansour and R. Storer, *Curr. Pharm. Des.*, 1997, **3**, 227. (c) V. E. Marquez, *Adv. Antiviral Drug Des.*, 1996, **2**, 89.
3. (a) Y. Kajihara, H. Hashimoto, and S. Ogawa, *Carbohydr. Res.*, 1999, **323**, 44. (b) S. Ogawa, N. Matsunaga, H. Li, and M. M. Palcic, *Eur. J. Org. Chem.*, 1999, 631. (c) S. Ogawa, T. Furuya, H. Tsunoda, O. Hindsgaul, K. Stangier, and M. M. Palcic, *Carbohydr. Res.*, 1995, **271**, 197.
4. K. Tadano, H. Kimura, M. Hoshino, S. Ogawa and T. Suami, *Bull. Chem. Soc. Jpn.*, 1987, 60, 3673.
5. C. Kaneko, A. Sugimoto, and S. Tanaka, , *Synthesis*, 1974, 876.

6. U. R. Kalkote, S. R. Ghorpade, R. R. Joshi, T. Ravindranathan, K. B. Bastawade, and D. V. Gokhale, *Tetrahedron: Asymmetry*, 2000, **11**, 2965.
7. L. A. Agrofoglio, I. Gillaizeau, and Y. Saito, *Chem. Rev.*, 2003**, 103**, 1875.
8. B. M. Trost, R. Madsen, S. D Guile, and B. Brown, *J. Am. Chem. Soc.*, 2000, **122**, 5947.
9. C. H. Behrens and K. Barry Sharpless, *J. Org. Chem.*, 1985**, 50**, 5696.
10. (a) D. R. Mootoo, Peter Konradsson, U. Udodong, and B. Fraser-Reid, *J. Am. Chem. Soc.*, 1988, **110**, 5583. (b) P. Konradsson, D. R. Mootoo, R. E. McDevitt, and B. Fraser-Reid, *J. Chem. Soc., Chem. Commun.*, 1990, 270. (c) B. Fraser-Reid, U. E Udodong, Z. Wu, H. Ottosson, J. R. Merritt, C. S. Rao, C. Roberts, and R. Madsen, *Synlett*, 1992, 927.