Tetrahedron: *Asymmetry* 20 (2009) 1217–1223

Contents lists available at ScienceDirect

Tetrahedron: *Asymmetry*

journal homepage: www.elsevier.com/locate/tetasy

A short and common stereoselective approach to 5/6, 6/6, 6/7 bicyclic aza sugars

B. Chandrasekhar [a], B. Venkateswara Rao [a,*], K. Veera Mohana Rao [b], B. Jagadeesh [b]

[a] *Organic Division III, Indian institute of Chemical Technology, Hyderabad 500607, India*
[b] *Nuclear Magnetic Resonance Division, Indian Institute of Chemical Technology, Hyderabad 500607, India*

ARTICLE INFO

Article history:
Received 10 February 2009
Accepted 10 March 2009
Available online 8 June 2009

ABSTRACT

An efficient and highly stereoselective approach to bicyclic aza sugars is described using Grignard reaction on an *N*-benzyl imine derived from 3-*O*-benzyl-1,2-*O*-isopropylidine-α-D-*xylo*-pentodialdofuranose, ring closing metathesis, and reductive cyclization as key steps.

1. Introduction

Polyhydroxylated derivatives of nitrogen heterocycles have attracted considerable interest due to their anticancer, antiviral, and antidiabetes activities.[1] Members of this class include nojirimycin, 1-deoxynojirimycin (DNJ), Castanospermine, and their derivatives. These imino sugars can inhibit various glycosidases because of their structural resemblance to the sugar moiety of natural substrates. Possibly this specificity is connected with the substitution pattern of the α–δ region and it may serve as a recognition pattern in the substrate–enzyme interaction.[2] DNJ **1** was first reported to have antiviral activity against both moloney murine leucamia virus and HIV-I. *N*-Alkyl substitution of DNJ was reported to enhance glycosidase I inhibitor activity and the *N*-methyl and *N*-butyl derivatives were shown to be more potent than the parent molecule at inhibiting HIV-induced syncytia.[3] *N*-Butyl-1-deoxy nojirimycin **2a** is an inhibitor of ceramide-specific glycosyl transferase and has been approved for the oral treatment of substrate reduction therapy in type-I gaucher disease.[4] *N*-Hydroxy ethenyl-1-deoxynojirimycin **2b**, which corresponds to the D-glucose configuration, has been approved as a second-generation glycosidase inhibitor to treat type-II diabetes.[5]

The bicyclic iminosugars having a six-membered ring system are analogues of Nojirimycin and 1-deoxy nojirimycin and are also known to show a variety of biological activities. Castanospermine **3** isolated from *castanospermum australe*[6] shows high anticancer, antiviral, and anti retroviral activities.[7] 6-*O*-Butanoyl castanospermine an acylated derivative of the parent compound **3** was found to have enhanced potency against HIV and moloney murine leucamia virus.[8] Because of their important biological activity and increasing popularity as new therapeutic agents, several approaches have been developed for their synthesis.[9,10] In particular the preparation of unnatural epimers and other structural analogues of these compounds created much interest, since the biological activity of these compounds varies substantially with the number, position, and stereochemistry of the hydroxy groups in the parent skeletons.[11]

These reports and our interest in the area of azasugars prompted us to explore the development of a general synthetic method which includes considerable flexibility for the construction of several bicyclic azasugars starting from carbohydrates.

In the past few years, our laboratory demonstrated the merit and potency of ring-closing metathesis (RCM) in the construction of carbocycles, azasugars, and oxygenated heterocycles from commercially available starting materials.[12] Earlier we utilized a stereoselective Grignard addition reaction on chiral imines for the synthesis of important bioactive compounds and the combination of a Grignard reaction on chiral imines and RCM was utilized for the construction of polyhydroxylated pyrrolidines.[12c,d,13] In order to expand the utility of this reaction in the construction of bicyclic iminosugars herein we report the stereoselective synthesis of acetyl derivatives of bicyclic azasugars (5,6), (6,6), and (6,7) such as 1-deoxy-castanospermine **4**, trihydroxy quinolizidine **5,** and novel trihydroxy pyrido-azepene **6** by using a Grignard addition on *N*-benzyl amine-derived imine, ring closing metathesis, and reductive cyclization reactions as key steps. Several approaches to 1-deoxy-castanospermine **4**[14] and trihydroxy quinolizidine **5**[15] are reported; to the best of our knowledge trihydroxy (6,7) bicyclic azasugar **6** is not reported in the literature (Fig. 1).

2. Results and discussion

The key aspect of our strategy is the synthesis of chiral amines **9a**–**d** and their elaboration to all of the target compounds based on our strategy. These amines are envisaged to derive from the sugar imine **8** by appropriate nucleophilic addition; chiral imine **8** in turn can be obtained from aldehyde **7**.[16] Generally the nucleophilic addition of organometallic reagents to carbon–nitrogen double bonds constitutes an extremely useful method for preparing a variety of amines.[17] Earlier compounds **9a** and **9c** are prepared by

* Corresponding author. Tel./fax: +91 40 27193003.
E-mail addresses: venky@iict.res.in, drb.venky@gmail.com (B. Venkateswara Rao).

0957-4166/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tetasy.2009.03.038

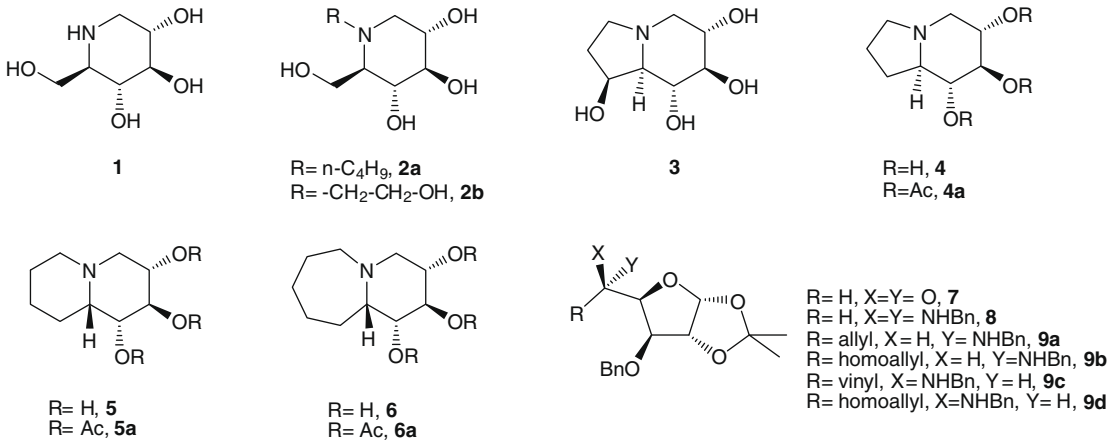
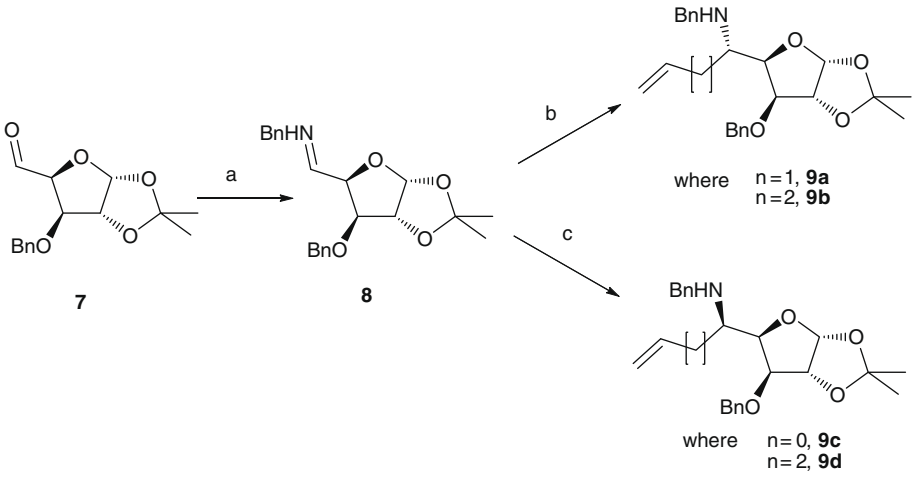


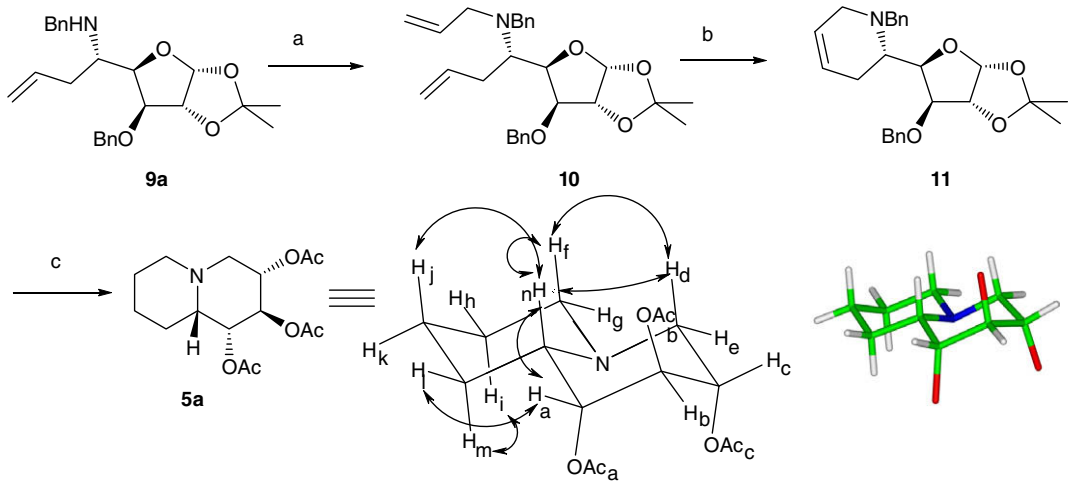
Figure 1.

nucleophilic addition to nitro imine derived from aldehyde **8** with poor diastereoselectivity;[15b,18b] efforts to improve the selectivity in the presence of Lewis acids were not that successful.[18] By utilizing the above reaction Dhavale et al. developed a nice approach for the synthesis of castanospermine, deoxy castanospermine, and other molecules, but the above procedure requires more manipulations to synthesize the required target as well as the separation of isomers.[15,19] Van Boom et al. and Martin et al. independently developed nucleophilic addition onto sugar imines derived from galactopyranose and sarbofuranose.[20] After their successful approach, to the best of our knowledge, little exploitation of this reaction was reported on different sugar imines. As an extension of our earlier strategy,[12c,d] that is, utilization of stereoselective Grignard addition and RCM for the synthesis of nitrogen heterocycles, it was felt that the nucleophilic addition onto imines such as **8** would give direct access to amines **9a–d** in a single step and also that imine **8** can be prepared conveniently from inexpensive glucose diacetonide. In order to study the stereochemical outcome in the Grignard reaction on imine **8** we initially under took the synthesis of triacetoxy quinolizidine **5a**.

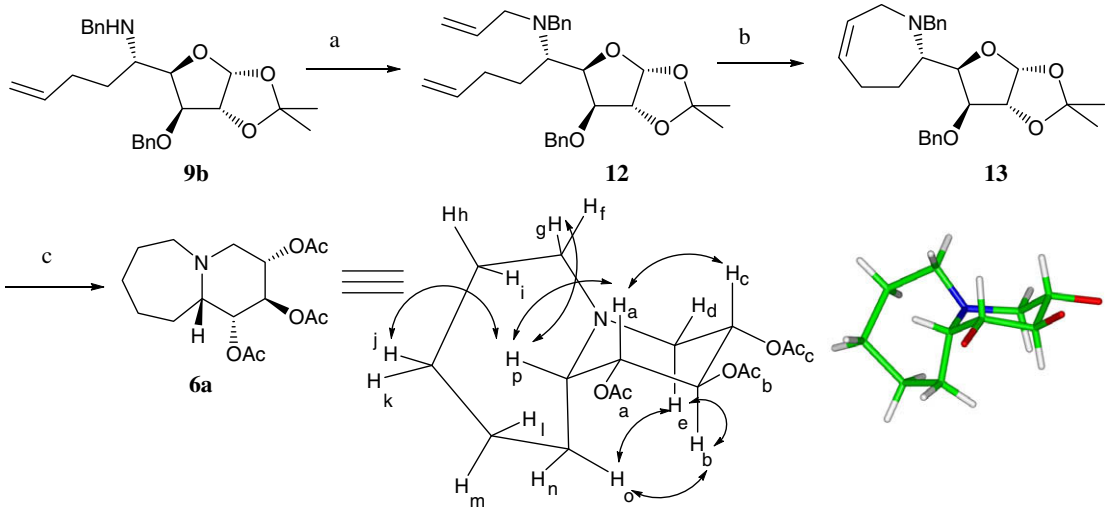
The benzylimine **8** was prepared by condensation of aldehyde **7** with benzyl amine in the presence of 4 Å molecular sieves in DCM. This was used as such without any purification. Treatment of imine **8** with allylmagnesium bromide at 0 °C gave the amino olefin **9a** as an exclusive diastereoisomer in 95% yield (Scheme 1). The absolute configuration of the newly created stereogenic center in compound **9a** was found to be *syn* whose spectral data were identical with the reported values.[15b] The excellent stereoselectivity observed in this reaction can be rationalized in terms of chelation-controlled mode with the formation of cyclic intermediate **I** (Fig. 2).[17] Blocking of the *re*-face of the imine functionality by the *O*-benzyl group and the presence of ring oxygen chelation might have helped the nucleophile addition to proceed with high selectivity. Allylation of amino olefin **9a** under standard reaction conditions gave diene **10**. This diene **10**, on reaction with Grubbs' first generation catalyst in DCM, afforded the desired heterocyclic ring on the sugar moiety.[21] Finally 1,2-*O*-isopropylidine deprotection of compound **11** by treatment with aq TFA gave the corresponding lactol. In order to achieve N,O-debenzylation, olefin reduction followed by reductive cyclization in a single pot, the lactol was treated with reducing agents such as Pd/C and $Pd(OH)_2$, even in the presence of a variety of hydrogen donors such as formic acid and ammonium formate which all failed to give the desired bicyclic skeleton. Then we tried the removal of benzyl groups and reduction of the double bond with Pd/C on compound **11** followed by acetonide deprotection and reductive amination with $NaBH_3CN$, but this also gave mixtures of compounds. Finally reacting the crude TFA treated product with a 1:1 mixture of Pd/C, and $Pd(OH)_2$ in dry ethanol condition[22] circumvented the problem and gave bicyclic tri hydroxy quinolizidine **5** in 70% yield from compound **11** (Scheme 2). This compound was



Scheme 1. Reagents and conditions: (a) $BnNH_2$, 4 Å molecular sieves, DCM; (b) allylmagnesium bromide, ether, 0 °C (or) homoallylmagnesium bromide, THF, 0 °C; (c) $BF_3{\cdot}OEt_2$, vinylmagnesium bromide, THF, −78 °C (or) $BF_3{\cdot}OEt_2$, homoallylmagnesium bromide, THF, −78 °C.



Scheme 2. Reagents and conditions: (a) NaH, allyl bromide, DMF, rt; (b) Grubbs' first generation catalyst, DCM, rt; (c) (i) TFA/H_2O (3:2), then H_2, Pd/Pd $(OH)_2$ (1:1), EtOH, rt; (ii) Ac_2O, Et_3N, DCM, rt.



Scheme 3. Reagents and conditions: (a) NaH, allyl bromide, DMF, rt; (b) Grubbs first generation catalyst, DCM, rt; (c) (i) TFA/H_2O (3:2), then H_2, Pd/Pd $(OH)_2$ (1:1), EtOH, rt; (ii) Ac_2O, Et_3N, DCM, rt.

characterized by converting into acetylated derivative **5a** in a conventional manner. In structure **5a** $J_{Hn–Ha}$ = 3.4 Hz with a strong NOE confirms that they are spatially closer to each other with *cis* conformation and $J_{Hn–Hm}$ = 11.6 Hz further confirms the axial orientation of these protons. The strong NOE cross-peaks between H_i–H_m, H_l–H_a, H_n–H_j, H_n–H_f, H_n–H_d, and H_f–H_d support the *syn* relationship of these two protons and also confirm the structure depicted in **5a**.

A hybrid bicyclic (6,7) molecule **6a** which is a homologue of trihydroxy quinolizidine analogue **5a** was also prepared from imine **8.** Treatment of **8** with homoallylmagnesium bromide at 0 °C gave *syn* adduct **9b** as the exclusive isomer in 70% yield (Scheme 1), the stereochemistry of this compound was not conformed at this stage. The olefin compound was converted to novel bicyclic (6,7) azasugars **6a** using a similar reaction pathway, as used for compound **5a** and the stereochemistry of the newly created center in compound **6a** was conformed from 2D-NMR techniques (Scheme 3). In structure **6a** $J_{Ha–Hp}$ = 5.4 Hz with strong NOE confirms that they are spatially closer with a *cis*-conformation. The strong NOE cross-peaks between H_b–H_o, H_b–H_e, H_e–H_o, H_a–H_c, H_p–H_g, and H_p–H_j confirm the structure of molecule **6a**.

Successfully preparing the bicyclic systems (6,6) and (6,7) the next task was to synthesize deoxy castanospermine **4** a trihydroxy indolizidine alkaloid. Chiral imine **8**, on reaction with vinylmagnesium bromide at various temperatures (0, −40, −78 °C) failed to give good selectivity. The poor diasteroselectivity in this reaction may be because of size of the reactive vinyl magnesium bromide. In order to improve the diastereoselectivity the nucleophilic addition was conducted in the presence of Lewis acid.[20] To the benzylimine derivative **8** in THF was added $BF_3{\cdot}Et_2O$ at −78 °C followed by vinylmagnesium bromide at −78 °C to give the single diasteromer **9c** in 70% yield (Scheme 1). The newly introduced stereocenter in compound **9c** was established to have the *anti* configuration by comparing it with the reported values.[18b] The excellent stereoselectivity observed in this reaction can be rationalized according to open transition state II (Fig. 2) with a rigid antiperiplanar conformation due to electrostatic repulsion.[20] Allylation, ring closing metathesis, and 1,2-*O*-isopropylidine cleavage followed by reductive cyclization of compound **9c** as described for **5a** gave the desired 1-deoxy castanospermine **4**. This was converted to its acetylated derivative **4a** by using Ac_2O, Et_3N whose physical properties are in good agreement with the reported values (Scheme 4).[14b] Structure **4a** $J_{Hk–Hl}$ = 9.3 Hz with weak range NOE confirms that they are spatially far and are in *trans* position. The observed NOE cross-peaks between H_j–H_h, H_l–H_h, H_l–H_j, H_l–H_d, H_a–H_e, H_a–H_k, and H_k–H_i support the structure of the molecule **4a** with an *anti*-arrangement of H_k–H_l protons.

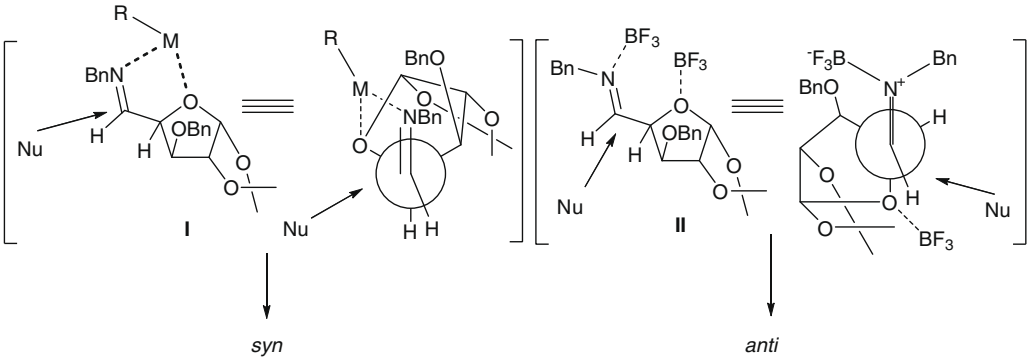
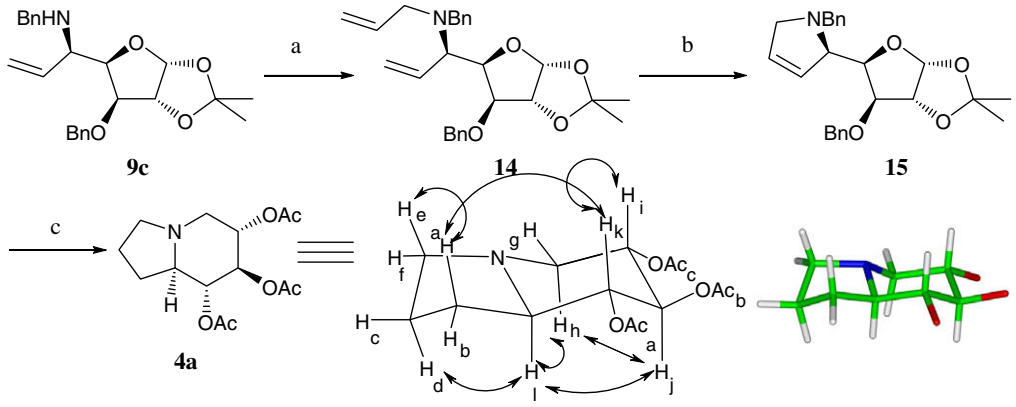


Figure 2.



Scheme 4. Reagents and conditions: (a) NaH, allyl bromide, DMF, rt; (b) Grubbs first generation catalyst, DCM, rt; (c) (i) TFA/H_2O (3:2), then H_2, Pd/Pd $(OH)_2$ (1:1), EtOH, rt; (ii) Ac_2O, Et_3N, DCM, rt.

In order to observe the reversal of stereo selectivity as observed by Martin et al.,[20] the chiral imine **8** was treated with homoallylmagnesium bromide in the presence of $BF_3{\cdot}OEt_2$ at −78 °C, and gave exclusively *anti*-isomer **9d** (Scheme 1). Elaboration of this will give the 10*a*-epimer of **6a**.

3. Conclusion

We have developed a short and efficient route for the synthesis of bicyclic azasugars with high stereoselectivity. This approach is general and useful for the preparation of various analogues of bicyclic azasugars, that is, indolizidines, quinolizidines, azepines, and pyrrolizidines. Its application in the synthesis of polyhydroxylated pyrrolizidines is in progress.

4. Experimental

4.1. General

TLC was performed on Merck Kiesel gel 60, F254 plates (layer thickness 0.25 mm). Column chromatography was performed on silica gel (60–120 mesh) using ethyl acetate and hexane mixture as eluent. Melting points were determined on a Fisher John's melting point apparatus and are uncorrected. IR spectra were recorded on a Perkin–Elmer RX-1 FT-IR system. ^{1}H NMR and ^{13}C NMR spectra were recorded using Bruker Avance-300 MHz, Varian-400, and 500 MHz spectrometers. ^{1}H NMR data are expressed as chemical shifts in ppm followed by multiplicity (s-singlet; d-doublet; t-triplet; q-quartet; m-multiplet), number of proton(s), and coupling constant(s) *J* (Hz). ^{13}C NMR chemical shifts are expressed in ppm. Optical rotations were measured with Horiba-SEPA-300 digital polarimeter. Accurate mass measurement was performed on Q STAR mass spectrometer (Applied Biosystems, USA). The bicyclic compounds are analyzed by using proton1D, homonuclear ^{1}H decoupling, and 2D NMR techniques such as DQF-COSY, TOCSY, and NOESY. Here the conformations are fixed by considering the observed J_s and NOEs.

4.1.1. *N*-Benzyl-(3a*R*,5*S*,6*S*,6a*R*)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro[2,3-*d*][1,3]dioxole-5-carbaldehyde 8

To a solution of aldehyde **7** (0.9 g, 3.23 mmol) in dry CH_2Cl_2 (10 mL) and molecular sieves 4 Å (200 mg) was added benzylamine (0.35 mL, 3.23 mmol) at room temperature and kept at 0 °C for 4 h. The reaction mixture was filtered and concentrated to give crude imine **8,** which was used as such for the next step.

4.1.2. (*S*)-*N*-Benzyl-1-((3a*R*,5*R*,6*S*,6a*R*)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro[2,3-*d*][1,3]dioxol-5-yl)but-3-en-1-amine 9a

To the solution of allyl magnesium bromide prepared from Mg (0.78 g, 32.4 mmol) and allyl bromide (1.37 mL, 16.2 mmol) in ether (20 mL) was added the solution of chiral imine **8** (1.19 g, 3.24 mmol) in ether over 10 min at 0 °C under nitrogen. After stirring overnight at room temperature, the mixture was poured into saturated NH_4Cl (50 mL) and extracted into ethylacetate (3 × 50 mL). The collected organic layers were combined, washed with water, brine, then dried over Na_2SO_4, concentrated under reduced pressure, and purified through column chromatography (hexane/ethyl acetate, 8:2) affording the corresponding amino olefin **9a** as a yellow oil (1.25 g, 95% for two steps). $[\alpha]_D^{30} = -55.6$ (*c* 0.52, CHC_3); IR $\nu_{max,}$ 2925, 1636,1455, 1076, 1025 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.4–7.14 (m, 10H), 5.88 (d, 1H, J = 4.2 Hz), 5.95–5.8 (m, 1H), 5.0 (m, 2H), 4.66 (d, 1H, J = 12 Hz), 4.57 (d, 1H,

J = 4.2 Hz), 4.43 (d, 1H, J = 12 Hz), 4.0 (dd, 1H, J = 9.1 and 3.0 Hz), 3.83 (m, 3H), 3.14 (m, 1H), 2.2 (m, 1H), 2.0 (m, 1H), 1.45, 1.3 (2s, 6H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 140.8, 137.2, 135.3, 128.5, 128.3, 128.26, 128.0, 127.9, 126.7, 116.8, 111.5, 104.6, 82.7, 81.8, 81.6, 71.5, 55.4, 51.7, 34.8, 26.7, 26.3. ESIMS m/z: 410 $[M+H]^+$. Hrms (esi) Calcd for $C_{25}H_{32}NO_4$ $[M+H]^+$ 410.2331, found 410.2335.

4.1.3. (*S*)-*N*-Allyl-*N*-benzyl-1-((3a*R*,5*R*,6*S*,6a*R*)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro[2,3-*d*][1,3]dioxol-5-yl)but-3-en-1-amine 10

To an ice-cold solution of olefin compound **9a** (0.5 g, 1.22 mmol) in DMF was added NaH (0.097 g, 2.4 mmol) after 30 min, allylbromide (0.25 mL, 2.9 mmol) was added and stirred for 12 h at room temperature. The reaction was quenched with saturated NH_4Cl (25 mL) and extracted with ether (3 × 50 mL). The combined organic layers were collected, dried (Na_2SO_4), filtered, and concentrated in vacuo to give a crude oil. Purification of the residual product by chromatography (hexane/ethyl acetate, 9:1) afforded diene **10** in 90% yield (0.49 g). $[\alpha]_D^{30} = -38.6$ (c 0.95, $CHCl_3$); IR ν_{max} 3448, 2923, 1644, 1076 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.4–7.1 (m, 10H), 5.93 (d, 1H, J = 4.2 Hz), 5.87–5.72 (m, 2H), 5.12 (dd, 1H, J = 17 and 2 Hz), 4.98 (dd, 1H, J = 10 and 2 Hz), 4.92 (dd, 1H, J = 10 and 2 Hz), 4.87 (dd, 1H, J = 17 and 2 Hz), 4.64 (d, 1H, J = 12 Hz), 4.54 (d, 1H, J = 3.8 Hz), 4.40 (d, 1H, J = 12 Hz), 4.2 (dd, 1H, J = 9.8 and 3.0 Hz), 3.87 (d, 1H, J = 13.6 Hz), 3.76 (d, 1H, J = 13.6 Hz), 3.72 (d, 1H, J = 3.0 Hz), 3.38–3.2 (m, 3H), 2.15–2.0 (m, 1H), 1.84–1.73 (m, 1H), 1.48 (s, 3H), 1.32 (s, 3H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ 141.3, 138.3, 137.4, 137.2, 129, 128.4, 127.9, 127.8, 127.5, 126.4, 115.9, 115.2, 111.3, 104.9, 82.6, 81.9, 81.2, 71.3, 56.9, 55.0, 53.3, 34.5, 26.8, 26.3. ESIMS m/z: 450 $[M+H]^+$. Hrms (esi) Calcd for $C_{28}H_{36}NO_4$ $[M+H]^+$ 450.2644, found 450.2631.

4.1.4. (*S*)-1-Benzyl-2-((3a*R*,5*R*,6*S*,6a*R*)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro[2,3-*d*][1,3]dioxol-5-yl)-1,2,3,6-tetrahydropyridine 11

Diene **10** (0.25 g, 0.55 mmol) was dissolved in dry CH_2Cl_2 (200 mL). Grubbs' first generation catalyst (0.046 g, 0.055 mmol) was added and the resulting purple solution turned brown after 10 min. The reaction mixture was stirred at room temperature for 12 h, concentrated in vacuo, and the residue was purified by column chromatography (hexane/ethyl acetate, 8:2) to give title compound **11** as a light brown oil (0.21 g, 90%). $[\alpha]_D^{30} = -25.2$ (c 0.25, $CHCl_3$); IR ν_{max} 2925, 1638, 1454, 1377, 1076 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.45–7.14 (m, 10H), 5.94 (d, 1H, J = 3.8 Hz), 5.6 (m, 2H), 4.67 (d, 1H, J = 11.7 Hz), 4.53 (d, 1H, J = 3.8 Hz), 4.46 (dd, 1H, J = 9.8 and 3.0 Hz), 4.40 (d, 1H, J = 11.7 Hz), 3.97 (d, 1H, J = 14 Hz), 3.84 (d, 1H, J = 14 Hz) 3.72 (d, 1H, J = 3.0 Hz), 3.52–3.42 (m, 1H), 3.22–3.07 (m, 2H), 2.46–2.33 (m, 1H), 1.73–1.6 (m, 1H), 1.45, 1.31 (2s, 6H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ 140.4, 137.3, 128.34, 127.9, 127.8, 127.6, 126.4, 125.7, 123.5, 111.3, 105.1, 82.7, 81.1, 78.4, 71.5, 58.4, 54.3, 47.0, 29.6, 26.8, 26.3. ESIMS m/z: 422 $[M+H]^+$. Hrms (esi) Calcd for $C_{26}H_{32}NO_4$ $[M+H]^+$ 422.2331, found 422.2338.

4.1.5. (1*R*,2*R*,3*S*,9a*S*)-Octahydro-1*H*-quinolizine-1,2,3-triyltriacetate 5a

The heterocyclic olefin compound **11** (0.1 g, 0.237 mmol) was treated with 2 mL of TFA:H_2O (3:2) at 0 °C then the reaction mixture was warmed to room temperature and stirred for 3 h. Solvents were removed by three co-evaporations with toluene (10 mL), and the residual product was taken into dry ethanol and to it 1:1 Pd/C and $Pd(OH)_2$ (100 mg) was added then the flask was purged with H_2 and hydrogenated at room temperature for 48 h. The reaction mixture was filtered and the filtrate was concentrated under reduced pressure to give syrup, which was acetylated with Ac_2O (0.12 mL, 1.18 mmol) and Et_3N (0.34 mL, 2.37 mmol) in DCM (5 mL) at 0 °C for 12 h. The reaction mixture was diluted with DCM (25 mL) and washed with saturated NH_4Cl (25 mL), dried over Na_2SO_4, and concentrated in vacuo to give crude product, which on purification by column chromatography (hexane/ethyl acetate 7:3) gave triacetate derivative **5a** (50 mg, 70% from **11**). $[\alpha]_D^{30} = +8.4$ (c 1.3, $CHCl_3$); IR ν_{max} 2925, 2855, 1744, 1232, 1046 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 4.93 (t, 1H, $J_{Hb-Ha,\ Hb-Hc}$ = 3.4 Hz, H_b), 4.87 (q, 1H, $J_{Hc-Hb,\ Hc-He,\ Hc-Hd}$ = 3.4 Hz, H_c), 4.81 (t, 1H, $J_{Ha-Hn,\ Ha-Hb}$ = 3.4 Hz, H_a), 2.94 (dd, 1H, J_{He-Hc} = 3.4 Hz, J_{He-Hd} = 13.2 Hz, H_e), 2.88 (m, 1H, H_g), 2.50 (dd, 1H, J_{Hd-Hc} = 3.4 Hz, J_{Hd-He} = 13.2 Hz, H_d), 2.38 (dt, 1H, $J_{Hn-Hl,\ Hn-Ha}$ = 3.4 Hz, J_{Hn-Hm} = 11.6 Hz, H_n), 2.13 (s, 3H, OAc_a), 2.12 (s, 3H, OAc_b), 2.10 (m, 4H, H_f, OAc_c), 1.81 (m, 1H, H_k), 1.72 (m, 1H, H_i), 1.54 (m, 2H, H_h, H_m), 1.42 (m, 1H, H_l), 1.32 (m, 1H, H_j). ^{13}C NMR ($CDCl_3$, 100 MHz) δ 170.4, 170.2, 168.7, 70.1, 67.9, 67.1, 59.2, 56.3, 54.0, 26.0, 24.2, 24.1, 21.3, 20.9, 20.8. ESIMS m/z: 314 $[M+H]^+$. Hrms (esi) Calcd for $C_{15}H_{24}NO_6$ $[M+H]^+$ 314.1603, found 314.1590.

4.1.6. (*S*)-*N*-Benzyl-1-((3a*R*,5*R*,6*S*,6a*R*)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro[2,3-*d*][1,3]dioxol-5-yl)pent-4-en-1-amine 9b

Compound **8** was treated with homoallyl magnesium bromine according to the procedure described for the preparation of **9a**. Purification of crude product of the reaction mixture by silica gel column chromatography (hexane/ethyl acetate, 8:2) provided title compound 9b as a yellow oil. (70% for two steps). $[\alpha]_D^{30} = -30.5$ (c 0.85, $CHCl_3$); IR ν_{max} 2923, 2854, 1644, 1076 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.37–7.13 (m, 10H), 5.88 (d, 1H, J = 3.8 Hz), 5.77–5.6 (m, 1H), 4.97–4.84 (m, 2H), 4.68 (d, 1H, J = 12.1 Hz) 4.57 (d, 1H, J = 3.8 Hz), 4.42 (d, 1H, J = 11.7 Hz), 4.1 (dd, 1H, J = 9.0 and 3.0 Hz), 3.82 (d, 1H, J = 3.4 Hz), 3.77 (s, 2H), 3.13–3.04 (m, 1H), 2.2–2.1 (m, 2H), 1.46 (s, 3H), 1.3(s, 3H), 1.44–1.21 (m, 2H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ 140.8, 138.7, 137, 128.5, 128.3, 128.2, 128, 127.9, 126.7, 114.4, 111.4, 104.6, 82.5, 81.8, 81.7, 71.6, 55.1, 51, 29.4, 29.3, 26.7, 26.2. ESIMS m/z: 424 $[M+H]^+$. Hrms (esi) Calcd for $C_{26}H_{34}NO_4$ $[M+H]^+$ 424.2487, found 424.2471.

4.1.7. (*S*)-*N*-Allyl-*N*-benzyl-1-((3a*R*,5*R*,6*S*,6a*R*)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro[2,3-*d*][1,3]dioxol-5-yl)pent-4-en-1-amine 12

The olefin compound **9b** was treated with NaH and allyl bromide according to the procedure described for **10** to give compound **12** in 80% yield. $[\alpha]_D^{30} = -57.6$ (c 4.3, $CHCl_3$); IR ν_{max} 3068, 2927, 1639, 1076 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.37–7.11 (m, 10H), 5.94 (d, 1H, J = 3.7 Hz), 5.88–5.73 (m, 1H), 5.66–5.5 (m, 1H), 5.12 (d, 1H, J = 17 Hz) 5.0 (d, 1H, J = 10 Hz), 4.84 (dd, 1H, J = 17 and 1.5 Hz), 4.78 (d, 1H, J = 10 Hz) 4.65 (d, 1H, J = 11.7 Hz), 4.53 (d, 1H, J = 3.8 Hz), 4.37 (d, 1H, J=11.7 Hz), 4.2 (dd, 1H, J = 10.2 and 2.6 Hz), 3.87 (d, 1H, J = 13.6 Hz), 3.75 (d, 1H, J = 13.6 Hz), 3.71 (d, 1H, J = 3.0 Hz), 3.27 (d, 2H, J = 6.4 Hz), 3.17 (dt, 1H, J = 2.6 and 11.3 Hz), 2.38–2.23 (m, 1H), 1.98–1.83 (m, 1H), 1.48 (s, 3H), 1.32 (s, 3H), 1–0.84 (m, 2H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ 141.3, 139, 138.3, 137.1, 129, 128.3, 127.8, 127.7, 127.6, 126.2, 115.9, 113.9, 111.1, 82.4, 82.2, 81, 71.3, 56.1, 55, 53.1, 30.1, 29, 26.7, 26.2. ESIMS m/z: 464 $[M+H]^+$. Hrms (esi) Calcd for $C_{29}H_{38}NO_4$ $[M+H]^+$ 464.2800, found 464.2798.

4.1.8. (*S*)-1-Benzyl-2-((3a*R*,5*R*,6*S*,6a*R*)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro[2,3-*d*][1,3]dioxol-5-yl)-2,3,4,7-tetrahydro-1*H*-azepine 13

The title compound **13** was obtained from **12** in 80% yield following the procedure used for the preparation of **11**. $[\alpha]_D^{30} = -155.6$ (c 0.25, $CHCl_3$); IR ν_{max} 2925, 1670, 1452, 1374, 1075, 1020 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.4–7.1 (m, 10H), 5.94 (d, 1H, J = 3.7 Hz), 5.81–5.7 (m, 1H), 5.47–5.37 (m, 1H), 4.68 (d, 1H, J = 11.7 Hz) 4.58 (d, 1H, J = 3.7 Hz), 4.41 (d, 1H, J = 12 Hz), 4.2 (dd,

1H, J = 9.4 and 3.0 Hz), 3.91 (d, 1H, J = 13.6 Hz), 3.78 (d, 1H, J = 13.6 Hz), 3.75 (d, J = 3.7 Hz), 3.47–3.28 (m, 2H), 3.03 (dd, 1H, J = 4.9 and 17.3 Hz), 2.38–2.2 (m, 1H), 2.2–2.06 (m, 1H), 1.61–1.5 (m, 2H), 1.45 (s, 3H), 1.35 (s, 3H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ 140.7, 137.3, 131.6, 129.3, 128.9, 128.4, 128, 127.9, 127.7, 126.5, 111.2, 104.8, 82.1, 81.5, 80.5, 71.4, 63.1, 56.1, 47.1, 29.6, 27.5, 26.7, 26.3. ESIMS m/z: 436 $[M+H]^+$.

4.1.9. (1*R*,2*R*,3*S*,10a*S*)-Decahydropyrido[1,2-a]azepine-1,2,3-triyl triacetate 6a

Compound **6a** was prepared from **13** in 70% yield, following the procedure described for **5a**. $[\alpha]_D^{30} = +3.3$ (c 0.9, $CHCl_3$); IR ν_{max} 2927, 1746, 1228, 1034 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.19 (t, 1H, $J_{Hb-Ha,\ Hb-Hc}$ = 9.2 Hz, H_b), 4.95 (dd, 1H, J_{Ha-Hp} = 5.4 Hz, J_{Ha-Hb} = 9.2 Hz, H_a), 4.87 (dt, 1H, J_{Hc-Hd} = 5.6 Hz, $J_{Hc-Hb,\ Hc-He}$ = 9.2 Hz, H_c), 3.23 (m, 1H, H_p), 2.99 (dt, 1H, $J_{Hf-Hh,\ Hf-Hi}$ = 4.2 Hz, J_{Hf-Hg} = 14.6 Hz, H_f), 2.93 (dd, 1H, J_{Hd-Hc} = 5.6 Hz, J_{Hd-He} = 11.7 Hz, H_d), 2.86 (m, 1H, H_g), 2.77 (dd, 1H, J_{He-Hc} = 9.2 Hz, J_{He-Hd} = 11.7 Hz, H_e), 2.04 (s, 3H, OAc), 2.03 (s, 3H, OAc), 2.02 (s, 3H, OAc), 1.80 (m, 1H, H_o), 1.75–1.60 (m, 4H, H_n, H_l, H_k, H_h), 1.59–1.48 (m, 3H, H_n, H_o, H_p). ^{13}C NMR ($CDCl_3$, 100 MHz) δ 170.2, 170.15, 170.0, 72.7, 71.1, 70.5, 59.8, 55.6, 48.0, 29.6, 26.8, 25.7, 24.3, 20.9, 20.8. ESIMS m/z: 328 $[M+H]^+$. Hrms (esi) Calcd for $C_{16}H_{26}NO_6$ $[M+H]^+$ 328.1760, found 328.1765.

4.1.10. (*R*)-*N*-Benzyl-1-((3a*R*,5*R*,6*S*,6a*R*)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro[2,3-*d*][1,3]dioxol-5-yl)prop-2-en-1-amine 9c

To the solution of vinyl magnesium bromide prepared from Mg (0.78 g, 32.4 mmol) and vinyl bromide (1.2 mL, 16.2 mmol) in THF (20 mL) was added the premixed solution of chiral imine **8** (1.19 g, 3.24 mmol) and $BF_3{\cdot}OEt_3$ (2 mL, 16.2 mmol) in THF (20 mL) over 10 min at −78 °C under nitrogen. After stirring overnight at room temperature, the reaction was quenched with saturated NH_4Cl (50 mL) and diluted with ethyl acetate (100 mL) and washed several times with aq $NaHCO_3$. The collected organic layers were combined, washed with water and brine, then dried over Na_2SO_4, concentrated under reduced pressure, and purified through column chromatography (hexane/ethyl acetate, 8:2) to give olefin **9c** in 70% (overall yield for two steps) as a colorless oil. $[\alpha]_D^{30} = -15.1$ (c 0.62, $CHCl_3$); IR ν_{max} 3449, 2930, 1455, 1075 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.32–7.12 (m, 10H), 5.85 (d, 1H, J = 3.8 Hz), 5.82–5.67 (m, 1H), 5.3–5.2 (m, 2H), 4.68 (d, 1H, J = 11.7 Hz), 4.55–4.48 (m, 2H), 4.02 (d, 1H, J = 3.0 Hz), 3.95 (dd, 1H, J = 3.0 and 8.8 Hz), 3.82 (d, 1H, J = 13.0 Hz), 3.59–3.46 (m, 2H), 1.45 and 1.28 (2s, 6H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ 140.1, 137.57, 137.3, 128.4, 128.2, 128.0, 127.8, 127.7, 126.7, 117.8, 111.3, 104.8, 82.4, 81.7, 81.4, 71.8, 59.0, 50.9, 26.6, 26.2. ESIMS m/z: 396 $[M+H]^+$. Hrms (esi) Calcd for $C_{24}H_{30}NO_4$ $[M+H]^+$ 396.2174, found 396.2159.

4.1.11. (*R*)-*N*-Allyl-*N*-benzyl-1-((3a*R*,5*R*,6*S*,6a*R*)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro[2,3-*d*][1,3]dioxol-5-yl)prop-2-en-1-amine 14

The title compound **14** was prepared in 90% yield according to the procedure used for the synthesis of **10**. $[\alpha]_D^{30} = -16.8$ (c 0.475, $CHCl_3$); IR ν_{max} 3068, 2928, 1638, 1452, 1076 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.34–7.1 (m, 10H), 5.97–5.8 (m, 1H), 5.82 (d, 1H, J = 3.8 Hz), 5.77–5.62 (m, 1H), 5.36 (dd, 1H, J = 10.3 and 2.0 Hz), 5.20 (dd, 1H, J = 17 and 1.8 Hz), 5.06 (d, 1H, J = 16.8 Hz), 4.93 (d, 1H, J = 10.1 Hz), 4.63 (d, 1H, J = 11.9 Hz), 4.53 (d, 1H, J = 11.9 Hz), 4.45 (d, 1H, J = 3.8 Hz), 4.24 (dd, 1H, J = 3.0 and 8.8 Hz), 3.98 (d, 1H, J = 3.0 Hz), 3.82 (d, 1H, J = 13.9 Hz), 3.7 (t, 1H, J = 8.8 Hz), 3.4 (d, 1H, J = 13.9 Hz), 3.17 (dd, 1H, J = 14.0 and 5.0 Hz), 2.96 (dd, 1H, J = 14.0 and 7.7 Hz), 1.42, 1.25 (2s, 6H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 140.1, 137.7, 136.9, 132.9, 128.5, 128.3, 128.2, 127.6, 127.5, 126.8, 119.8, 116.9, 111.3, 104.8, 81.8, 81.6, 80.3, 71.9, 59.9, 54.7, 54.3, 26.7, 26.1. ESIMS m/z: 436 $[M+H]^+$. Hrms (esi) Calcd for $C_{27}H_{34}NO_4$ $[M+H]^+$ 436.2487, found 436.2484.

4.1.12. (*R*)-1-Benzyl-2-((3a*R*,5*R*,6*S*,6a*R*)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro[2,3-*d*][1,3]dioxol-5-yl)-2,5-dihydro-1*H*-pyrrole 15

Treatment of compound **14** with Grubbs' first generation catalyst following the same procedure described for **11** gave compound **15** as a yellow liquid in 90% yield. $[\alpha]_D^{30} = -9.2$ (c 1.2, $CHCl_3$); IR ν_{max} 3063, 2985, 2928, 1452, 1376, 1076, 1021 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.34–7.1 (m, 10H), 5.99–5.89 (m, 1H), 5.86 (d, 1H, J = 4.2 Hz), 5.8–5.7 (m, 1H), 4.62 (d, 1H, J = 11.3 Hz), 4.56 (d, 1H, J = 3.8 Hz), 4.36 (d, 1H, J = 11.7 Hz), 4.15–4.0 (m, 3H), 3.9 (dd, 1H, J = 8.7 and 3.0 Hz), 3.8–3.67 (m, 1H), 3.55 (d, 1H, J = 14.0 Hz), 3.25–3.13 (m, 1H), 1.49 (s, 3H), 1.30 (s, 3H). ^{13}C NMR ($CDCl_3$ 100 MHz) δ 140.4, 137.2, 129.8, 128.4, 128.2, 128.1, 127.8, 127.6, 127.5, 126.6, 111.5, 104.8, 84.5, 81.9, 81.4, 71.3, 68.8, 61.1, 60.2, 26.7, 26.3. ESIMS m/z: 408 $[M+H]^+$. Hrms (esi) Calcd for $C_{25}H_{30}NO_4$ $[M+H]^+$ 408.2174, found 408.2165.

4.1.13. 6,7,8-Triacetyl, 1-deoxy, castanospermine 4a

Triacetoxy indolizidine **4a** was obtained from **15** in 70% yield using a similar reaction sequence used for the preparation of **5a**. $[\alpha]_D^{30} = +38.3$ (c 0.36, $CHCl_3$); IR ν_{max} 2980, 2831, 1745, 1225, 1034 cm^{-1}; ^{1}H NMR (C_6D_6, 500 MHz) δ 5.34 (t, 1H, $J_{Hj-Hi,\ Hj-Hk}$ = 9.3 Hz, H_j), 5.31 (dt, 1H, J_{Hi-Hg} = 5.0 Hz, $J_{Hi-Hj,\ Hi-Hh}$ = 9.3 Hz, H_i), 5.13 (t, 1H, $J_{Hk-Hl,\ Hk-Hj}$ = 9.3 Hz, H_k), 3.11 (dd, 1H, J_{Hg-Hi} = 5.0 Hz, J_{Hg-Hh} = 10.2 Hz, H_g), 2.63 (dt, 1H, J_{He-Hc} = 2.8 Hz, $J_{He-Hf,\ He-Hd}$ = 8.5 Hz, H_e), 1.91 (dt, 1H, J_{Hl-Hb} = 6.5 Hz, $J_{Hl-Hk,\ Hl-Ha}$ = 9.3 Hz, H_l), 1.85 (dd, 1H, J_{Hh-Hi} = 9.3 Hz, J_{Hh-Hg} = 10.2 Hz, H_h), 1.79 (m, 1H, H_f), 1.76 (s, 3H, OAc), 1.73 (s, 3H, OAc), 1.68 (s, 3H, OAc), 1.60 (m, 1H, H_b), 1.56–1.53 (m, 2H, H_a, H_d), 1.30 (m, 1H, H_c). ^{13}C NMR (C_6D_6 100 MHz) δ 169.9, 169.4 (st), 75.4, 74.6, 71.1, 65.5, 52.9, 52.7, 28.2, 22.2, 20.4, 20.38. ESIMS m/z: 300 $[M+H]^+$. Hrms (esi) Calcd for $C_{14}H_{22}NO_6$ $[M+H]^+$ 300.1447, found 300.1458.

4.1.14. (*R*)-*N*-Benzyl-1-((3a*R*,5*R*,6*S*,6a*R*)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro[2,3-*d*][1,3]dioxol-5-yl)pent-4-en-1-amine 9d

The title compound **9d** was obtained from **8** in 70% yield following the similar procedure used for the preparation of **9c.** $[\alpha]_D^{30} = -34.5$ (c 0.575, $CHCl_3$); IR ν_{max} 3368, 2931, 1639, 1454, 1076 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.28–7.13 (m, 10H), 5.89–5.74 (m, 1H), 5.86 (d, 1H, J = 3.7 Hz), 5.03–4.88 (m, 2H), 4.67 (d, 1H, J = 11.7 Hz), 4.54 (d, 1H, J = 4 Hz), 4.48 (d, 1H, J = 11.7 Hz), 4.0–3.94 (m, 2H), 3.74 (q, 2H, J = 12.8 Hz), 3.14–3.06 (m, 1H), 2.26–2.06 (m, 2H), 1.87–1.76 (m, 1H), 1.66–1.55 (m, 1H), 1.46 (s, 3H), 1.3 (s, 3H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ 140.88, 138.88, 137.31, 128.43, 128.25, 127.99, 127.86, 127.75, 126.76, 114.4, 111.3, 104.7, 82.34, 81.8, 81.67, 71.7, 54.38, 51.3, 30.29, 29.32, 26.7, 26.22. ESIMS m/z: 424 $[M+H]^+$.

Acknowledgments

B.C. and K.V. thank the CSIR, New Delhi, for research fellowship. We also thank Dr. J.S. Yadav and Dr. A.C. Kunwar for their support and encouragement. We also thank DST (SR/S1/OC-14/2007), New Delhi, for financial support.

References

1. For a review, see: Asano, N.; Nash, R. J.; Molyneux, R. J.; Fleet, G. W. J. *Tetrahedron: Asymmetry* **2000**, *11*, 1645.
2. (a) Trugnan, G.; Rousset, M.; Zweibaum, A. *FEBS Lett.* **1986**, *195*, 28; (b) Hempel, A.; Camerman, N.; Mastropaolo, D.; Camerman, A. *J. Med. Chem.* **1993**, *36*, 4082;

(c) Stutz, A. E. *Iminosugars as Glycosidase Inhibitors: Nojirimycin and Beyond*; Wiley-VCH: Weinheim, 1999; (d) Watson, A. A.; Fleet, G. W. J.; Asano, N.; Molyneux, R. J.; Nash, R. J. *Phytochemistry* **2001**, *56*, 265; (e) Lillelund, V. H.; Jensen, H. H.; Liang, X.; Bols, M. *Chem. Rev.* **2002**, *102*, 515.
3. Gruters, R. A.; Neefjes, J. J.; Jersmette, M.; de Goede, R. E. Y.; Tulp, A.; Huisman, H. G.; Miedema, F.; Ploegh, H. L. *Nature* **1987**, *300*, 74.
4. (a) Cox, T.; Lachaman, R.; Hollack, C.; Aerts, J.; Van Weely, S.; Heerbicek, M.; Plat, F.; Butters, T. D.; Dwek, R.; Moyses, C.; Gow, I.; Elstein, D.; Zimrean, A. *Lancet* **2000**, *355*, 1481; (b) Butters, T. D.; Dwek, R. A.; Platt, F. M. *Chem. Rev.* **2000**, *100*, 4683; (c) Butters, T. D.; van den Brock, L. A. G. M.; Fleet, G. W. J.; Krulle, T. M.; Wormald, M. R.; Dwek, R. A.; Platt, F. M. *Tetrahedron* **2000**, *11*, 1113; (d) Butters, T. D.; Dwek, R. A.; Platt, F. M. *Curr. Top. Med. Chem.* **2003**, *3*, 561.
5. Mitrakou, A.; Tountas, N.; Raptis, A. E.; Bauer, R. J.; Schulz, H.; Raptis, S. A. *Diabetes Med.* **1998**, *15*, 657.
6. Hohenschutz, L. D.; Bell, E. A.; Jewess, P. J.; Leworthy, D. P.; Pryce, R. J.; Arnold, E.; Clardy, J. *Phytochemistry* **1981**, *20*, 811.
7. (a) Fleet, G. W. J.; Karpas, A.; Dwek, R. A.; Fellows, L. E.; Tyms, A. S.; Petursson, S.; Namgoong, S. K.; Ramsden, N. G.; Smith, P. W.; Son, J. C.; Wilson, F.; Witty, D. R.; Jacob, G. S.; Rademacher, T. W. *FEBS Lett.* **1988**, *237*, 128; (b) Pili, R.; Chang, J.; Partis, R. A.; Mueller, R. A.; Chrest, F. J.; Passaniti, A. *Cancer Res.* **1995**, *55*, 2920.
8. (a) Taylor, D. L.; Sunkara, P. S.; Lin, P. S.; Kang, M. S.; Bowlin, T. L.; Tyms, A. S. *AIDS* **1991**, *5*, 693; (b) Taylor, D. L.; Kang, M. S.; Brennan, T. M.; Bridges, C. G.; Sunkara, P. S.; Tyms, A. S. *Antimicrob. Agents Chemother.* **1994**, 1780.
9. (a) Iida, H.; Yamazaki, N.; Kibayashi, C. *J. Org. Chem.* **1987**, *52*, 3337; (b) Straub, A.; Effenberger, F.; Fisher, P. *J. Org. Chem.* **1990**, *55*, 3926; (c) Liotta, L. J.; Lee, J.; Ganem, B. *Tetrahedron* **1991**, *47*, 2433; (d) Johnson, C. R.; Golebiowski, A.; Sundram, H.; Miller, M. W.; Dwainy, R. L. *Tetrahedron Lett.* **1995**, *36*, 653; (e) Duff, F. J.; Vivien, V.; Wightman, R. H. *Chem. Commun.* **2000**, 2127; (f) Cheng, X.; Kumaran, G.; Mootoo, D. R. *Chem. Commun.* **2001**, 811; (g) Boglio, C.; Stahike, S.; Thorimbert, S.; Malacria, M. *Org. Lett.* **2005**, 4851; (h) Pearson, M. S. M.; Mathé-Allainmat, M.; Fargeas, V.; Lebreton, J. *Eur. J. Org. Chem.* **2005**, 2159; (i) Afarinkia, K.; Bahar, A. *Tetrahedron: Asymmetry* **2005**, *16*, 1239.
10. (a) Burgess, K.; Henderson, I. *Tetrahedron* **1992**, *48*, 4045; (b) Ina, H.; Kibayashi, C. *J. Org. Chem.* **1993**, *58*, 52; (c) Kim, N. S.; Choi, J. C.; Cha, J. K. *J. Org. Chem.* **1993**, *58*, 709; (d) Zaho, H.; Hans, S.; Cheng, X.; Mootoo, D. R. *J. Org. Chem.* **2001**, *66*, 1761; (e) Machan, T.; Davis, A. S.; Liawruangrath, B.; Pyne, S. G. *Tetrahedron* **2008**, *64*, 2725. and references cited therein.
11. (a) Mulzer, J.; Dehmlow, H. *J. Org. Chem.* **1992**, *57*, 3194; (b) Maggini, M.; Prato, M.; Ranelli, M.; Scorrano, G. *Tetrahedron Lett.* **1992**, *45*, 6537; (c) Kang, S.; Kim, J. S. *Chem. Commun.* **1998**, 1353; (d) Asano, N.; Yasuda, K.; Kizu, H.; Kato, A.; Fan, J.-Q.; Nash, R. J.; Fleet, G. W. J.; Molyneux, R. J. *Eur. J. Biochem.* **2001**, *268*, 35; (e) O' Doherty, G. A.; Haukaas, M. H. *Org. Lett.* **2001**, *3*, 401; (f) Gopal Reddy, B.; Vankar, Y. D. *Angew. Chem., Int. Ed.* **2005**, *44*, 2001; (g) Alam, M. A.; Kumar, A.; Vankar, Y. D. *Eur. J. Org. Chem.* **2008**, 4872.
12. (a) Bhaskar, G.; Rao, B. V. *Tetrahedron Lett.* **2003**, *44*, 915; (b) Ramana, G. V.; Rao, B. V. *Tetrahedron Lett.* **2003**, *44*, 5103; (c) Madhan, A.; Rao, B. V. *Tetrahedron Lett.* **2003**, *44*, 5641; (d) Chandrasekhar, B.; Madhan, A.; Rao, B. V. *Tetrahedron* **2007**, *63*, 8746.
13. Madan, A.; Ravikumar, A.; Rao, B. V. *Tetrahedron: Asymmetry* **2001**, *12*, 2009.
14. (a) Hendry, D.; Hough, L.; Richardson, A. C. *Tetrahedron Lett.* **1987**, 4597; (b) Hendry, D.; Hough, L.; Richardson, A. C. *Tetrahedron* **1988**, *44*, 6143; (c) Aamlid, K. H.; Hough, L.; Richardson, A. C. *Carbohydrate Res.* **1990**, *202*, 117; (d) Denis, Y. S.; Chan, T.-H. *J. Org. Chem.* **1992**, *57*, 3078; (e) Martin, S. F.; Chen, H.-J.; Yang, C.-P. *J. Org. Chem.* **1993**, *58*, 2867; (f) Martin, S. F.; Chen, H.; Lynch, V. M. *J. Org. Chem.* **1995**, *60*, 276; (g) Yoda, H.; Nakajima, T.; Takabe, K. *Synlett* **1997**, 911; (h) Izquierdo, I.; Plaza, M. T.; Robels, R.; Rodriguez, C.; Ramirez, A.; Mota, A. J. *Eur. J. Org. Chem.* **1999**, *64*, 1269; (i) Denis, Y. S.; Chan, T.-H. *Can. J. Chem.* **2000**, *78*, 776.
15. (a) Overkleeft, H. S.; Bruggeman, P.; Pandit, U. P. *Tetrahedron Lett.* **1998**, *39*, 3869; (b) Dhavale, D. D.; Jachak, S. M.; Karche, N. P.; Trombini, C. *Tetrahedron* **2004**, *60*, 3009; (c) Dhavale, D. D.; Jachak, S. M.; Karche, N. P.; Trombini, C. *Synlett* **2004**, 1549.
16. Wolfrom, M. L.; Hanessian, S. *J. Org. Chem.* **1962**, *27*, 1800.
17. Bloch, R. *Chem. Rev.* **1998**, *98*, 1407.
18. (a) Dhavale, D. D.; Desai, V. N.; Sindkhedkar, M. D.; Mali, R. S.; Castellari, C.; Trombini, C. *Tetrahedron: Asymmetry* **1997**, *8*, 1475; (b) Merino, P.; Anaro, S.; Franco, S.; Gascon, J. M.; Martin, V.; Merchan, F. L.; Revuelta, J.; Tejero, T.; Tunon, V. *Synth. Commun.* **2000**, *30*, 2989.
19. (a) Saha, N. N.; Desai, V. N.; Dhavale, D. D. *Tetrahedron* **2001**, *57*, 39; (b) Patil, N. T.; Tilekar, J. N.; Dhavale, D. D. *Tetrahedron Lett.* **2001**, 747; (c) Patil, N. T.; Tilekar, J. N.; Dhavale, D. D. *J. Org. Chem.* **2001**, *66*, 1067; (d) Dhavale, D. D.; Jachack, S. M. *Molecules* **2005**, *10*, 893; (e) Karanjule, N. S.; Markand, S. D.; Shinde, V. S.; Dhavale, D. D. *J. Org. Chem.* **2006**, *71*, 4667.
20. (a) van Delft, F. L.; de Kort, M.; vander Marel, G. A.; van Boom, J. H. *J. Org. Chem.* **1996**, *61*, 1883; (b) Godin, G.; Compain, P.; Masson, G.; Martin, O. R. *J. Org. Chem.* **2002**, *67*, 6960; (c) Bordier, A.; Compain, P.; Martin, O. R.; Ideka, K.; Asano, N. *Tetrahedron: Asymmetry* **2003**, *14*, 47.
21. Selected examples of some azasugars using Grubbs catalyst (a) White, J. D.; Hrnciar, P.; Yokochi, A. F. T. *J. Am. Chem. Soc.* **1998**, 7359; (b) Pandit, U. K.; Overkleeft, H. S.; Borer, B. C.; Bieraugel, H. *Eur. J. Org. Chem.* **1999**, 959; (c) Felpin, F.-X.; Lebreton, J. *Eur. J. Org. Chem.* **2003**, 3693; (d) Verhelst, S. H. L.; Martinez, B. P.; Timmer, M. S. M.; Lodder, G.; vander Marel, G. A.; Overkleeft, H. S.; van Boom, J. H. *J. Org. Chem.* **2003**, *68*, 9598; (e) Karanjule, N. S.; Markad, S. D.; Dhavale, D. D. *J. Org. Chem.* **2006**, *71*, 6273; (f) Ritthiwigrom, T.; Pyne, S. G. *Org. Lett.* **2008**, *10*, 2769; (g) Muroni, D.; Mucedda, M.; Saba, A. *Tetrahedron Lett.* **2008**, *49*, 2373.
22. Li, Y.; Manickam, G.; Ghoshal, A.; Subramaniam, P. *Synth. Commun.* **2006**, *36*, 2925.