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Theeraphan Machan
*University of Wollongong, tmachan@uow.edu.au*

Andrew S. Davis
*University of Wollongong*

Boonsom Liawruangrath
*Chiang Mai University*

Stephen G. Pyne
*University of Wollongong, spyne@uow.edu.au*

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Synthesis of Castanospermine

Theeraphan Machan¹², Andrew S. Davis¹, Boonsom Liawruangrath² and Stephen G. Pyne¹*

¹School of Chemistry, University of Wollongong, Wollongong, New South Wales, 2522, Australia
²Department of Pharmaceutical Science, Faculty of Pharmacy, Chiang Mai University,
Chiang Mai 50200, Thailand

spyne@uow.edu.au

Dedication: This paper is dedicated to E. J. Corey in the year of his 80th birthday.

Abstract: The diastereoselective synthesis of castanospermine is described in 11 synthetic steps from L-xylose. The borono-Mannich reaction between L-xylose, allylamine and (E)-stylene boronic acid gives a tetrahydroxy amine with the desired configurations for C-6, C-7, C-8 and C-8a in the target molecule. A novel pyrrolo[1,2-c]oxazol-3-one precursor was employed to allow for the control of π-facial diastereoselectivity in an osmium(VIII)-catalysed syn-dihydroxylation (DH) reaction. A regioselective ring-opening of the cyclic sulfate derivative of the resulting diol then secured the C-1 hydroxyl group of castanospermine with the correct configuration. A Mitsunobu cyclization then provided di-O-benzyl castanospermine and ultimately the final target alkaloid.

1. Introduction

The indolizidine alkaloid castanospermine 1 was first isolated from the seeds of Castanospermum australe¹ and then from the dry pods of Alexa leiopetala.² Castanospermine is a potent inhibitor of several glucosidases³ and has potential for the treatment of viral infections,⁴ cancers,⁵ and diabetes.⁶ In addition it shows anti-inflammatory⁷ and immunosuppressant⁸ properties. Recent in vitro studies have demonstrated that 1 was able to prevent mortality in mice infected with dengue virus.⁹ Because of its unique structure and biological activities many syntheses of castanospermine have been reported.¹⁰ As part of our program concerned with the synthesis of
polyhydroxylated indolizidine and pyrrolizidine alkaloids\textsuperscript{11-19} we report here a 11-step synthesis of castanospermine from L-xylose. This synthesis demonstrates the versatility and flexibility of our earlier synthetic strategy for preparing polyhydroxyindolizidines.\textsuperscript{17}

![Figure 1. Structure of castanospermine (1).](image)

### 2. Results and Discussion

The known amino-tetraol \textsuperscript{2,17} obtained from the borono-Mannich reaction of L-xylose, allylamine and (\textit{E})-styrene boronic acid, was converted to oxazolidin-2-one \textsuperscript{3} upon treatment with triphosgene under basic conditions (Scheme 1).\textsuperscript{13,14} The triol \textsuperscript{4} was readily converted to its O-trityl derivative \textsuperscript{4} in 87% yield under standard conditions.\textsuperscript{17} Under basic O-benzylation reaction conditions\textsuperscript{17} compound \textsuperscript{4} gave a mixture of the corresponding di-O-benzyl-oxazolidin-2-one \textsuperscript{5} and the oxazin-2-one \textsuperscript{6} (Scheme 1). These could be separated by column chromatography to provide pure samples of \textsuperscript{5} and \textsuperscript{6} in yields of 56% and 22%, respectively, however this separation was difficult. Treatment of \textsuperscript{5} with Grubbs’ second generation ruthenium catalyst\textsuperscript{19} gave the pyrrolo[1,2-c]oxazol-3-one \textsuperscript{7} in 88% yield. Alternatively, \textsuperscript{7} could be more readily obtained by treating a mixture of \textsuperscript{5} and \textsuperscript{6} with Grubbs’ second generation ruthenium catalyst followed by a relatively easier separation of \textsuperscript{7} (68%) from the pyrrolo[1,2-c]oxazin-1-one \textsuperscript{8} (20%) (Scheme 1).
Scheme 1

Ph-CHB(OH)₂
L-xylene
\[ \rightarrow \]
\[ \rightarrow \] 2
\( \text{NaH, BnBr, Bu₄NI} \)
THF, 50 °C, 4d
87%

\[ \text{TrCl, pyridine} \]
rt, 20 h
87%

\[ \text{Grubbs' II cat.} \]
\( \text{CH}_2\text{Cl}_2, \)
reflux 48 h
88%

\[ \text{Grubbs' II cat.} \]
\( \text{CH}_2\text{Cl}_2, \)
reflux 48 h
88%
Based on our previous work,\textsuperscript{13,14,19} and that of Parsons,\textsuperscript{20,21} we expected that the \textit{syn}-dihydroxylation (DH) of 7 would furnished the corresponding diol with the desired stereochemistry for the synthesis of the target alkaloid. In the event, the osmium(VIII)-catalysed \textit{syn}-DH of 7 furnished the desired diol 9 accompanied by 17\% of its diastereomeric diol in 84\% yield after purification of the crude reaction mixture by column chromatography (Scheme 2). Separation of this mixture by further column chromatography gave diastereomerically pure 9 in 60\% yield and 6,7-\textit{di-epi}-9 in 16\% yield. The diol 9 was then converted to the cyclic sulfate 10 in 64\% overall yield by first treatment with thionyl chloride under basic conditions to give the corresponding cyclic sulfite followed by oxidation at sulfur with catalytic ruthenium tetroxide (RuCl$_3$, NaIO$_4$).\textsuperscript{13,22} Regioselective reductive ring-opening of 10 with sodium borohydride\textsuperscript{10(f)} in dimethylacetamide (DMA) at rt for 6 h followed by acid hydrolysis of the resulting adduct gave the diol 11 in 63\% yield in which the O-trityl group had also been cleaved (Scheme 2). Base catalysed hydrolysis of the oxazolidinone ring of 11 under microwave irradiation conditions gave the pyrrolidine 12 in 80\% yield which was readily separated from the unexpected cyclized product, the furan derivative 13 (16\% yield). \textbf{We have not unequivocally proved the structure of 13.} However this compound is also produced as a byproduct from the Mitsunobu reaction of 12 in Scheme 3. The most likely mechanism for the formation of 13 in the latter reaction is a shown in Scheme 3 via initial activation of the primary hydroxyl. We therefore speculate that 13 arises from 11 (Scheme 2) via cyclizaion of the incipient alkoxide ion that is generated from collapse of the initial tetrahedral intermediate formed from addition of hydroxide ion to the carbonyl group of the oxazolidinone moity of 11. This incipient alkoxide intermediate then attacks the carbon of the terminal methylene of the side chain to displace hydroxide ion and give the furan ring.
Scheme 2

7 $\xrightarrow{\text{dr} = 83 : 17}$ 9 (84%)

(i) SOCl$_2$, Et$_3$N, CH$_2$Cl$_2$
(ii) RuCl$_3$, NaIO$_4$
64%

(i) NaBH$_4$, DMA, rt, 6 h
(ii) H$_2$SO$_4$, H$_2$O, THF, rt, 20 h
63%

NaOH, H$_2$O, MeOH, MW
110 $^\circ$C, 2 h
12 (80%) + 13 (16%)

K$_2$OsO$_4$-2H$_2$O, NMO, acetone/H$_2$O, rt, 48 h

10

64%
Attempts to cyclize the amino-triol 12 under Appel cyclization reaction conditions (Ph₃P/CBr₄/Et₃N)²³ were unsuccessful and a complex mixture of products resulted. Treatment of 12 under Mitsunobu reaction conditions²⁴ produced the desired indolizidine product 14 in 25% yield along with the furan 13 (22% yield) and the oxepino[3,2-b]pyrrole 15 (11% yield) (Scheme 3). These three isomeric compounds were readily distinguished by ¹³C and HMBC NMR experiments. The structure of the indolizidine 14 was clear from the relatively upfield ¹³C NMR methylene resonances at δ 54.2 (C-5) and 52.0 (C-2) for the methylenes directly attached to nitrogen. While the downfield methylene resonances at δ 72.0 (C-5′) and δ 72.2 (C-5) in 13 and 15, respectively were consistent with methylenes directly attached to oxygen in a ring system. HMBC NMR experiments on 13 demonstrated a 3-bond correlation between C-2′ and H-5′, such a correlation between the analogous carbon (C-8) and proton (H-5) in 15 would not be expected as this would represent a 4-bond correlation.

Debenzylation of 14 under hydrogenolysis conditions using PdCl₂/H₂²⁶ gave castanospermine 1 in 95% yield after ion-exchange chromatography (Scheme 3). The ¹H and ¹³C NMR spectral data of this compound matched very closely to that reported in the literature.¹ The optical rotation of this compound [α]₀²⁷ + 82 (c 1.2, H₂O) also agreed with that reported (lit.¹ [α]₀²⁴ + 79.7 (c 0.93, H₂O)). This sample was also identical to an authentic sample by TLC analysis.²⁷

Scheme 3

3. Conclusions
In conclusion we have successfully developed a diastereoselective synthesis of castanospermine in 11 synthetic steps from L-xylose using the borono-Mannich reaction to give a tetrahydroxy amine with the desired configurations for C-6, C-7, C-8 and C-8a in the target molecule. A novel pyrrolo[1,2-c]oxazol-3-one precursor was employed to allow for the control of \( \pi \)-facial diastereoselectivity in an osmium(VIII)-catalysed syn-dihydroxylation (DH) reaction. A regioselective ring-opening of the cyclic sulfate derivative of the resulting diol then secured the C-1 hydroxyl group of castanospermine with the correct configuration. A Mitsunobu cyclization then provided di-O-benzyl castanospermine and ultimately the final target alkaloid. This synthesis further demonstrates the versatility and flexibility of our earlier synthetic strategy for preparing polyhydroxyindolizidines.17

4. Experimental

General methods were as described previously.12,13 All \(^1\)H NMR spectra were performed at 500 MHz and all \(^{13}\)C NMR (DEPT) spectra at 125 MHz in CDCl\(_3\) solution, unless otherwise noted. NMR assignments are based on COSY, DEPT and HSQC NMR experiments and sometimes HMBC and NOESY experiments. IR spectra were determined as neat samples. Petrol refers to petroleum spirit bp 40-60 °C.

\[(4R,5R)-3\text{-Allyl-5-((1R,2S)-1,2,3-trihydroxypropyl)-4-((E)-2-phenyl-vinyl)-1,3-oxazolidin-2-one (3) and its 1,3-dioxolan-2-onyl derivative, (4R,5R)-3\text{-allyl-5-(((4S)-1,3-dioxolan-2-onyl)-hydroxymethyl)-4-((Z)-2-phenylvinyl)-1,3-oxazolidin-2-one.}\]

To a solution of the amino alcohol \(2^{17}\) (4.560 g, 15.56 mmol) in dry THF (400 mL) was added triethylamine (4.3 mL, 31.13 mmol) and then triphosgene (1.390 g, 4.68 mmol). The mixture was stirred at rt for 10 h, followed by the evaporation of all volatiles \textit{in vacuo}. The residue was suspended in water (100 mL) and extracted with ethyl acetate (3 x 100 mL). The combined organic extracts were dried (MgSO\(_4\)) and filtered then concentrated \textit{in vacuo} to give a yellow solid. Chromatography of the crude product and eluting with 90-100% EtOAc/petrol and then 2% MeOH/EtOAc gave compound 3 as a white crystalline solid (2.65 g, 53%, \(R_f = 0.20\), 2% MeOH/EtOAc). \([\alpha]_D^{27} -10\) (c 4.5, MeOH). Mp
141 °C. IR ν\text{max}/\text{cm}^{-1} 3550, 2950, 2914, 1737, 1447, 1094, 1041. MS (ESI+) m/z 320 (M+H\textsuperscript{+}), 100%. \textsuperscript{1}H NMR (CD\textsubscript{3}OD) δ 3.57 (1H, dd, J = 11.3, 6.3 Hz, H3\textsuperscript{'''}) 3.60 (1H, app. ddt, J = 15.7, 6.7, 1.3 Hz, H1\textsuperscript{''''}), 3.65 (1H, dd, J = 11.3, 5.3 Hz, H3\textsuperscript{''}), 3.73 (1H, m, H2\textsuperscript{''}), 3.83 (1H, app. t, J = 4.3 Hz, H1\textsuperscript{''}), 4.01 (1H, app. ddt, J = 15.7, 4.7, 1.7 Hz, H1\textsuperscript{''''}), 4.61 (1H, app. t, J = 9.0 Hz, H4), 4.83 (1H, dd, J = 8.5, 4.0 Hz, H5), 5.20 (1H, dd, J = 10.0, 1.5 Hz, H3\textsuperscript{''''}), 5.22 (1H, dd, J = 17.5, 1.0 Hz, H3\textsuperscript{''''}), 5.79 (1H, m, H2\textsuperscript{''''}), 6.38 (1H, dd, J = 16.0, 9.5 Hz, H1\textsuperscript{'''}), 6.70 (1H, d, J = 16.0 Hz, H2\textsuperscript{'''}), 7.36 (5H, m, Ar-H). \textsuperscript{13}C NMR (CD\textsubscript{3}OD) δ 45.5 (CH\textsubscript{2}), 62.6 (CH), 64.1 (CH\textsubscript{2}), 70.9 (CH), 73.3 (CH), 78.9 (CH), 118.3 (CH), 124.2 (CH), 127.9 (2×Ar-CH), 129.4 (Ar-CH), 129.7 (2×Ar-CH), 133.4 (CH), 137.2 (C), 138.5 (CH), 159.8 (CO).

(4R,5R)-3-Allyl-5-((1R,2S)-1,2-dihydroxy-3-(triphenylmethyloxy)-propyl)-4-((E)-2-phenylvinyl)-1,3-oxazolidin-2-one (4).

To a solution of oxazolidinone 3 (2.42 g, 7.59 mmol) in anhydrous pyridine (40 mL) was added trityl chloride (3.17 g, 11.38 mmol). The mixture was stirred for 20 h at rt. The reaction was quenched with water (60 mL) then extracted with diethyl ether (3 x 80 mL). The combined organic phases were washed with saturated CuSO\textsubscript{4} (3 x 90 mL) and brine (90 mL), dried (MgSO\textsubscript{4}) and evaporated to give a yellow oil that was purified by column chromatography (30-50% EtOAc/petrol) to give compound 4 as a white foamy solid (3.68 g, 87%, R\textsubscript{f} = 0.20, 30% EtOAc/petrol). [α]\textsubscript{D}\textsuperscript{27} \text{= -18 (c 4.4, CHCl\textsubscript{3})}. IR ν\text{max}/\text{cm}^{-1} 3401, 3053, 3027, 2914, 1731, 1448, 1070. MS (ESI+) m/z 579 (M+NH\textsubscript{4}\textsuperscript{+}, 100%) ; HRMS (ESI+) calcld for C\textsubscript{36}H\textsubscript{35}NO\textsubscript{5}Na (M+Na\textsuperscript{+}) 584.2413, found 584.2419. \textsuperscript{1}H NMR δ 2.57 (1H, br.d, J = 5.0 Hz, OH1\textsuperscript{'''}), 2.82 (1H, br.d, J = 5.5 Hz, OH2\textsuperscript{'}), 3.18 (1H, dd, J = 10.0, 5.5 Hz, H3\textsuperscript{''}), 3.31 (1H, dd, J = 9.5, 5.0 Hz, H3\textsuperscript{'}), 3.54 (1H, dd, J = 15.5, 7.5 Hz, H1\textsuperscript{''''}), 3.90 (1H, br. t, J = 4.0 Hz, H2\textsuperscript{'''}), 3.96 (1H, br. d, J = 3.5 Hz, H1\textsuperscript{'}), 4.11 (1H, dd, J = 15.8, 6.5 Hz, H1\textsuperscript{''''}), 4.46 (1H, app. t, J = 9.3, Hz, H4), 4.55 (1H, dd, J = 8.8, 3.8 Hz, H5), 5.18 (1H, dd, J = 17.3, 1.0 Hz, H3\textsuperscript{''''}), 5.21 (1H, dd, J = 10.3, <1 Hz, H3\textsuperscript{''''}), 5.74 (1H, m, H2\textsuperscript{''''}), 6.32 (1H, dd, J = 16.0, 9.5 Hz, H1\textsuperscript{'''}), 6.61 (1H, d, J = 15.5 Hz, H2\textsuperscript{'''}),
9

7.39-7.19 (20H, m, Ar). $^{13}$C NMR δ 44.8 (CH$_2$), 61.1 (CH), 64.4 (CH$_2$), 69.9 (CH), 71.0 (CH), 77.3 (CH), 87.2 (C), 118.7 (CH), 123.0 (CH), 127.1-129.0 (20×Ar-CH), 132.1 (CH), 135.6 (Ar-C), 137.6 (CH), 143.7 (Ar-C), 157.2 (CO).

(4$R$,5$R$)-3-allyl-5-((1S,2S)-1,2-bis(benzyloxy)-3-(triphenylmethoxy)-propyl)-4-((E)-2-phenylvinyl)-1,3-oxazolidin-2-one (5), and (4$R$,5$R$,6$S$)-3-allyl-5-(benzyloxy)-6-((S)-1-(benzyloxy)-2-(triphenylmethoxy)-ethyl)-4-((E)-2-phenylvinyl)-1,3-oxazinan-2-one (6).

To a solution of 4 (4.403 g, 7.85 mmol) in dry THF (50 mL) was added 40% NaH in mineral oil (1.20 g, 19.62 mmol). After H$_2$ evolution had ceased (15 min), benzyl bromide (7.5 mL, 62.79 mmol) and tetrabutylammonium iodide (444 mg, 1.18 mmol) were added. The mixture was stirred for 24 h at rt, then treated with methanol (10 mL) and triethylamine (6 mL) and stirred for 15 min. All volatiles were removed in vacuo and the residue was dissolved in CH$_2$Cl$_2$, filtered through a pad of celite, followed by further washings of the solids with CH$_2$Cl$_2$. The filtrate was washed with water and brine and then dried (MgSO$_4$) and concentrated to give a yellow oil. The residue was purified by column chromatography (20-40% EtOAc/petrol) to yield two compounds, 5 as a yellow oil (3.258 g, 56%) and 6 as a yellow oil (1.299 g, 22%). Because of the similar polarity of the products ($R_f$ of 5 = 0.60 and $R_f$ of 6 = 0.55 in 40% EtOAc/petrol), they were used in the subsequent RCM reaction step without separation.

5: [α]$_D^{26}$ +52 (c 3.2, CHCl$_3$). IR $\nu$max/cm$^{-1}$ 3058, 3027, 2945, 2873, 1752, 1450, 1070. MS (ESI+) m/z 764 (M + Na$^+$, 85%), HRMS (ESI+) calcd for C$_{50}$H$_{47}$NO$_5$Na (M + Na$^+$) 764.3351, found 764.3378. $^1$H NMR (300 MHz) δ 3.32 (1H, dd, $J$ = 16.0, 7.5 Hz, H1$''$), 3.39 (1H, dd, $J$ = 9.5, 5.0 Hz, H3$'$), 3.44 (1H, dd, $J$ = 10.0, 5.0 Hz, H3$'$), 3.58 (1H, app. t, $J$ = 8.0 Hz, H4), 3.75 (1H, m, H2$'$), 4.01 (1H, J = dd, 7.5, 3.3 Hz, H1$'$), 4.08 (1H, app. dd, $J$ = 16.0, 4.5 Hz, H1$''$), 4.13 (1H, d, $J$ = 12.0 Hz, CH$_2$Ph), 4.60 (1H, d, $J$ = 11.4 Hz, CH$_2$Ph), 4.65 (1H, d, $J$ = 12.0 Hz, CH$_2$Ph), 4.79 (1H, app. t, $J$ = 7.4, Hz, H5), 4.85 (1H, d, $J$ = 11.1 Hz, CH$_2$Ph), 5.06 (1H, d, $J$ = 17.0 Hz, H3$'''$), 5.15 (1H, d, $J$ = 10.0 Hz, H3$'''$), 5.63
(1H, m, H2’’’), 5.93 (1H, d, J = 15.5 Hz, H2’’’), 5.99 (1H, dd, J = 16.0, 9.0 Hz, H1’’’), 7.35-7.09 (30H, m, Ar). 13C NMR δ 43.8 (CH2), 59.4 (CH), 60.6 (CH2), 70.7 (CH2), 74.3 (CH2), 74.4 (CH), 76.6 (CH), 77.2 (CH), 77.4 (CH), 86.6 (C), 117.7 (CH2), 121.0 (CH), 126.1-128.7 (30×Ar-CH) 131.9 (CH), 134.5, (Ar-C), 136.8 (CH), 137.4 (Ar-C), 137.7 (Ar-C), 143.2 (3 × Ar-C), 156.8 (CO).

6: [α]D26 +37 (c 1.2, CHCl3). MS (ESI+) m/z 764 (M+Na+, 100%) HRMS (ESI+) calc. for C50H47NO5Na (M+Na+) 764.3352, found 764.3364. 1H NMR (300 MHz) δ 2.92 (1H, dd, J = 10.7, 2.9 Hz, H2’’’), 3.34 (1H, app. ddt, J = 15.5, 7.7, 1.1 Hz, H1’’’’), 3.45 (1H, app. t, J = 1.8 Hz, H5), 3.57 (1H, d, J = 10.8 Hz, CH2Ph), 3.70 (1H, dd, J = 10.5, 1.8 Hz, H2’’’), 3.90 (1H, app dt, J = 7.8, 1.8 Hz, H1’’’), 4.08 (1H, app. dt, J = 6.3, 1.7 Hz, H4), 4.24 (1H, d, J = 11.1 Hz, CH2Ph), 4.60-4.52 (1H, m, H1’’’’), 4.70 (1H, d, J = 11.4 Hz, CH2Ph), 4.84 (1H, d, J = 11.4 Hz, CH2Ph), 4.93 (1H, dd, J = 7.8, 1.5 Hz, H6), 5.12 (1H, dd, J = 10.2, 1.5 Hz, H3’’’’), 5.16 (1H, dd, J = 17.4, 1.5 Hz, H3’’’’), 5.77 (1H, m, H2’’’’), 5.93 (1H, dd, J = 15.9, 6.3 Hz, H1’’’), 6.54 (1H, dd, J = 15.9, 1.5 Hz, H2’’’), 7.57-7.06 (30H, m, Ar). 13C NMR δ 50.0 (CH2), 57.9 (CH), 62.2 (CH), 71.6 (CH2), 73.2 (CH), 73.9 (CH2), 77.6 (CH), 79.3 (CH), 86.5 (C), 118.0 (CH2), 125.2 (CH), 127.2-129.1 (30×Ar-CH), 132.9 (CH), 134.1 (CH), 135.7 (Ar-C), 137.2 (Ar-C), 138.8 (Ar-C), 143.6 (3 × Ar-C), 153.2 (CO).

(1R,7aR)-1-((1S,2S)-1,2-Bis(benzyloxy)-3-(triphenylmethoxy)propyl)-1,7a-dihydropyrrolo[1,2-c]oxazol-3(5H)-one (7), and (3S,4R,4aR)-4-(benzyloxy)-3-((S)-1-(benzyloxy)-2-(triphenylmethoxy)-ethyl)-4,4a-dihydro-3H-pyrrolo[1,2-c] [1,3]oxazin-1(7H)-one (8).

Method 1: Synthesis of 7 from pure 6.

Grubbs’ II catalyst (105.2 mg, 0.124 mmol) was added to a solution of oxazolidinone 6 (918.8 mg, 1.240 mmol) in dry CH2Cl2 (150 mL) under nitrogen. The mixture was heated at reflux for 48 h, followed by cooling to rt and then removal of the solvent in vacuo to give a brown oil. The residue was purified by column chromatography (20-50% EtOAc/petrol) to give compound 7 (695.1 mg, 88%, Rf = 0.26, 30% EtOAc/petrol) as a white foamy solid.
**Method 2: Synthesis of 7 and 8 from a mixture of 6 and 7.**

Grubbs’ II catalyst (199 mg, 0.234 mmol) was added to a solution of the mixture of 6 and 7 (2.383 g, 3.22 mmol), obtained above from 4, in dry CH₂Cl₂ (350 mL) under nitrogen. The mixture was heated at reflux for 48 h, followed by cooling to rt and then removal of the solvent *in vacuo* to give a brown oil. The residue was purified by column chromatography (20-50% EtOAc/petrol) to give compound 7 (1.403 g, 68%, Rᵣ = 0.26, 30% EtOAc/petroleum ether) as a white foamy solid, and 8 (412.4 mg, 20%, Rᵣ = 0.07, 30% EtOAc/petrol) as a white foamy solid.

7: \([\alpha]_{D}^{25}\) +13 (c 4.5, CHCl₃). IR ν \(\max/cm^{-1}\) 3063, 3027, 2945, 2868, 1696, 1125, 1070, 1029. MS (ESI+) \(m/z\) 660 (M+Na⁺, 43%), HRMS (ESI+) calcd for C₄₂H₃₉NO₅Na (M+Na⁺) 660.2726, found 660.2712. \(^1\)H NMR δ 3.43 (1H, dd, \(J = 10.0, 4.8\) Hz, H₃'), 3.52 (1H, dd, \(J = 10.0, 5.0\) Hz, H₃'), 3.66-3.61 (1H, m, H₅), 3.69-3.70 (2H, m, H₁', H₂'), 4.04-4.08 (1H, m, H₇a), 4.22-4.27 (1H, m, H₅), 4.35 (1H, d, \(J = 11.5\) Hz, CH₂Ph), 4.58 (1H, d, \(J = 11.0\) Hz, CH₂Ph), 4.64 (1H, d, \(J = 11.5\) Hz, CH₂Ph), 4.71 (1H, d, \(J = 11.5\) Hz, CH₂Ph), 4.77 (1H, dd, \(J = 8.0, 6.0\) Hz, H₁), 5.65 (1H, app. dd, \(J = 6.0, 1.0\) Hz, H₆), 5.84 (1H, app. dd, \(J = 6.0, 1.5\) Hz, H₇), 7.43-7.12 (25H, m, Ar).

\(^{13}\)C NMR δ 54.7 (CH₂), 62.5 (CH₂), 67.0 (CH), 72.6 (CH₂), 74.6 (CH), 77.1 (CH), 78.3 (CH), 79.0 (CH), 87.4 (C), 126.2 (CH), 127.4-128.8 (25×Ar-CH), 131.7 (CH), 138.1(Ar-C), 138.2 (Ar-C), 144.0 (3 × Ar-C), 162.2 (CO).

8: \([\alpha]_{D}^{27}\) +67 (c 5.15, CHCl₃). IR ν \(\max/cm^{-1}\) 3052, 3027, 2924, 2863, 1685, 1105, 1096. MS (ESI+) \(m/z\) 660 (M+Na⁺, 42%), HRMS (ESI+) calcd for C₄₂H₃₉NO₅ (M⁺) 637.2828, found 637.2811. \(^1\)H NMR δ 3.51 (1H, dd, \(J = 10.0, 7.0\) Hz, H₂'), 3.54 (1H, dd, \(J = 10.0, 6.0\) Hz, H₂'), 3.60 (1H, dd, \(J = 10.0, 6.0\) Hz, H₄), 3.86 (1H, dddd, \(J = 7.2, 6.0, 1.5\) Hz, H₁'), 4.03 (1H, ddt, \(J = 16.0, 4.5, 1.5\) Hz, H₇), 4.40 (1H, dtt, \(J = 16.0, 4.5, 1.5\) Hz, H₇), 4.45 (1H, d, \(J = 11.5\) Hz, CH₂Ph), 4.52 (1H, dd, \(J = 9.8, 1.5\) Hz, H₄a), 4.57 (1H, d, \(J = 11.5\) Hz, CH₂Ph), 4.59 (1H, d, \(J = 11.5\) Hz, CH₂Ph), 4.60 (1H, d, \(J = 11.5\) Hz, CH₂Ph), 4.61(1H, dd, \(J = 6.0, 1.0\) Hz, H₃), 5.84 (2H, br. m, H₅, H₆), 7.43-7.20 (25H, m, Ar). \(^{13}\)C NMR δ 55.4
(1R,6S,7R,7aR)-1-((1S,2S)-1,2-Bis(benzyloxy)-3-(triphenylmethoxy)propyl)-tetrahydro-6,7-dihydroxypyrrolo[1,2-c]oxazol-3(1H)-one (9) and (1R,6R,7S,7aR)-1-((1S,2S)-1,2-bis(benzyloxy)-3-(triphenylmethoxy)-propyl)-tetrahydro-6,7-dihydroxypyrrolo[1,2-c]oxazol-3(1H)-one (6,7-di-epi-9).

To a solution of 7 (1.403 g, 2.203 mmol) in acetone (13.2 mL) and water (8.8 mL) was added potassium osmate dihydrate (57 mg, 0.15 mmol) and 4-morpholine N-oxide (516 mg, 4.41 mmol). The mixture was stirred at rt for 48 h followed by evaporation of all the volatiles to give a black oil. Purification by column chromatography (70–90% EtOAc/petrol) gave a mixture of diastereoisomeric dihydroxy products, 9 and 6,7-di-epi-9, as a white foamy solid (1.242 g, 84%, d.r. = 83 : 17). The isomers were separated using 2% MeOH/CH2Cl2 as an eluent on a silica gel column (1 cm diameter × 30 cm long) to give the pure compound 9 (894 mg, 60%) and compound 6,7-di-epi-9 (248 mg, 16%) (Rf of 9 = 0.33 and Rf of 6,7-di-epi-9 = 0.27, 2% MeOH/CH2Cl2).

9: [α]D27 +43 (c 3.5, CHCl3). IR νmax/cm⁻¹ 3411, 3058, 3027, 2914, 2848, 1734, 1745, 1093, 1055

**MS** (ESI+) m/z 694 (M+Na⁺, 100%) HRMS (ESI+) calced for C42H42NO7 (M+H⁺), 672.2961 found 672.3005.

1H NMR δ 2.57 (br, OH), 2.94 (1H, dd, J = 8.0, 2.0 Hz, H7a), 3.40 (1H, dd, J = 10.5, 4.8 Hz, H3’), 3.36 (1H, dd, J = 11.5, 8.0 Hz, H5), 3.29 (1H, dd, J = 11.5, 7.5 Hz, H5), 3.54-3.55 (2H, m, H3’, H7), 3.76, dd, J = 9.5, 5.0 Hz, H2’), 4.14 (1H, m, H6), 4.32 (1H, dd, J = 6.0, 4.5 Hz, H1’), 4.41 (1H, d, J = 12.0 Hz, CH2Ph), 4.64 (1H, dd, J = 7.5, 6.0 Hz, H1), 4.71 (1H, d, J = 11.0 Hz, CH2Ph), 4.73 (1H, d, J = 12.0 Hz, CH2Ph), 4.76 (1H, d, J = 11.0 Hz, CH2Ph), 7.44-7.18 (25H, m, Ar). 13C NMR δ 50.6 (CH2), 62.6 (CH2), 64.6 (CH), 70.8 (CH), 72.3 (CH2), 74.1 (CH), 75.0 (CH2), 76.6 (CH), 76.6 (CH), 77.4 (CH), 87.4 (C), 127.5-129.0 (25×Ar-CH ), 137.2 (Ar-C), 138.0 (Ar-C), 144.0 (3 × Ar-C), 162.1 (CO).
**6,7-di-epi-9:** \( \left[ \alpha \right]_{D}^{24} +24 \) (c 1.2, CHCl\(_3\)). IR \( \nu_{\max}/\text{cm}^{-1} \) 3412, 3058, 3027, 2930, 1731, 1447, 1095, 1053. MS (ESI+) \( m/z \) 694 (M+Na\(^{+}\), 100%). HRMS (ESI+) calecd for C\(_{42}\)H\(_{42}\)NO\(_7\) (M+H\(^{+}\)), 672.2961 found 672.3020. 1H NMR \( \delta \) 2.49 (1H, br, OH), 3.08 (1H, dd, \( J = 12.8, 1.8 \) Hz, H5), 3.34 (1H, dd, \( J = 9.0, 7.0 \) Hz, H7\( a \)), 3.44 (1H, dd, \( J = 10.0, 5.5 \) Hz, H3\( a \)), 3.53 (1H, dd, \( J = 10.0, 5.0 \) Hz, H3\( a' \)), 3.81 (1H, dd, \( J = 13.0, 5.5 \) Hz, H5), 3.83 (1H, m, H7), 3.96 (1H, dd, \( J = 8.0, 3.5 \) Hz, H1\( ' \)), 4.08-4.09 (2H, m, H2\( ' \), H6), 4.41 (1H, d, \( J = 12.0 \) Hz, CH\(_2\)Ph), 4.53 (1H, d, \( J = 11.0 \) Hz, CH\(_2\)Ph), 4.70 (1H, d, \( J = 11.5 \) Hz, CH\(_2\)Ph), 4.71 (1H, d, \( J = 11.5 \) Hz, CH\(_2\)Ph), 4.83 (1H, app. t, \( J = 7.5 \) Hz, H1), 7.44-7.14 (m, 25H), Ar). 13C NMR \( \delta \) 52.7 (CH\(_2\)), 62.2 (CH\(_2\)), 63.5 (CH), 70.0 (CH), 71.4 (CH), 72.5 (CH\(_2\)), 74.7 (CH), 76.2 (CH), 76.8 (CH), 77.2 (CH), 87.7(C), 127.5-129.1 (25×Ar-CH), 137.2 (Ar-C), 137.8 (Ar-C), 143.7 (3 \( \times \) Ar-C), 161.0 (CO).

(3\( aR \), 3b\( S \), 4\( R \), 8a\( S \))-Tetrahydro-4-((1\( S \),2\( S \))-1,2-bis(benzyloxy)-3-triphenylmethoxy)-propyl)-2,2-dioxide,5\( H \),4\( H \)-1,3,2-dioxathiolo[3,4]pyrrolo[1,2-c]oxazol-6-one (10).

To a solution of 9 (1.207 g, 1.80 mmol) in dry CH\(_2\)Cl\(_2\) (40 mL) was added triethylamine (4 mL, 28.78 mmol) and thionyl chloride (0.2 mL, 2.70 mmol). The mixture was stirred for 48 h at rt, and then water (50 mL) was added to the mixture. The aqueous layer was extracted with CH\(_2\)Cl\(_2\) (3 x 100 mL). The combined extracts were washed with brine and dried (MgSO\(_4\)) then evaporated under reduced pressure to give a brown foamy solid. The crude cyclic sulfite was used for the next step without further purification. The crude obtained above was dissolved in 50 mL of a solution of CCl\(_4\)/CH\(_3\)CN/H\(_2\)O (2 : 3 : 2, v/v/v) then NaIO\(_4\) (1.539 g, 7.12 mmol) and RuCl\(_3\).3H\(_2\)O (23.5 mg, 0.09 mmol) were added. The mixture was stirred for 3 h at rt and then diluted with diethyl ether (80 mL). The organic layer was filtered through a pad of celite. The filtrate was washed with brine and dried (MgSO\(_4\)). The solvent was removed \textit{in vacuo} then purified by column chromatography (30-70% EtOAc/petrol) to give compound 10 (849 mg, 64%, \( R_l = 0.49, 50\% \) EtOAc/petrol) as a white foamy solid. \( \left[ \alpha \right]_{D}^{27} +30.6 \) (c 7.5, CHCl\(_3\)). IR \( \nu_{\max}/\text{cm}^{-1} \) 3050, 3020, 2935, 2850, 1761, 1349, 1173, 1075. MS
(ESI-) m/z 732 (M-H+, 100%) HRMS (ESI+) calcd for C_{42}H_{39}NO_{9}SNa (M+Na+) 756.2243, found 756.2297. \(^1\)H NMR δ 3.15 (1H, dd, J = 15.0, 5.5 Hz, H8) 3.30 (1H, dd, J = 7.0, 3.5 Hz, H3b), 3.50-3.55 (2H, m, 2 x H3’), 3.56-3.60 (1H, m, H2’), 4.13 (1H, dd, J = 14.5, 1.0 Hz, H8), 4.26 (1H, dd, J = 9.5, 4.0 Hz, H1’), 4.29 (1H, d, J = 11.5 Hz, CH2Ph), 4.54 (1H, d, J = 11.5 Hz, CH2Ph), 4.58 (1H, d, J = 9.5 Hz, CH2Ph), 4.80 (1H, d, J = 5.5, 3.5 Hz, H3a), 4.84 (1H, d, J = 11.5 Hz, CH2Ph), 5.03-5.05 (2H, m, H4, H8a), 7.31 (25H, m, Ar-H). \(^13\)C NMR δ 50.2 (CH2), 61.5 (CH2), 63.5 (CH), 72.3 (CH2), 74.3 (CH2), 74.9 (CH), 77.0 (CH), 77.8 (CH), 83.6 (CH), 84.3 (CH), 87.8 (C), 127.3-129.0 (25×Ar-CH), 137.0 (Ar-C), 137.5 (Ar-C), 143.5 (3×Ar-C), 159.0 (CO).

(7S,7aR)-1-((1S,2S)-1,2-Bis(benzyloxy)-3-hydroxypropyl)-tetrahydro-7-hydroxypyrrolo[1,2-c]oxazol-3(1H)-one (11).

To a solution of 10 (689 mg, 0.940 mmol) in anhydrous N,N-dimethylacetamide (2.5 mL) was added NaBH4 (62 mg, 1.410 mmol). The reaction was stirred under nitrogen at rt for 6 h, then the N,N-dimethylacetamide was removed under reduced pressure and the residue was suspended in THF (30 mL). Water (1 mL) followed by concentrated H2SO4 (0.5 mL) was added, and the suspension became a clear solution. The solution was stirred for 48 h at rt followed by the addition of water (20 mL). The mixture was extracted with EtOAc (3 x 30 mL) and the combined extracts were washed with brine, dried (MgSO4) and concentrated. The residue was purified by column chromatography (5-10% MeOH/EtOAc) to give compound 11 (248 mg, 63%, Rf = 0.40, 8% MeOH/EtOAc) as a white foamy solid. [α]D\(^{28}\) +19 (c 16.6, CHCl3). IR νmax/cm\(^{-1}\) 3426, 3050, 2950, 2840, 1732, 1075, 1052. MS (ESI+) m/z 414 (M+H+, 100%). HRMS (ESI+) calcd for C_{23}H_{28}NO_{6} (M+H+) 414.1917, found 414.1926. \(^1\)H NMR δ 1.74 (1H, dddd, J = 13.5, 10.0, 10.0, 3.5 Hz, H6), 1.93 (1H, ddd, J = 13.5, 8.0, 2.0 Hz, H6), 3.11 (1H, br. d, J = 9.5 Hz, H7a), 3.14 (1H, dd, J = 7.5, 2.0 Hz, H5), 3.68 (1H, m, H5), 3.78-3.81 (2H, m, H2’, H3’), 3.89 (1H, dd, J = 11.0, 3.5 Hz, H3’), 3.93 (1H, app. br. s, H7), 4.20 (1H, app. t, J = 4.5 Hz, H1’), 4.54 (1H, d, J = 12.0 Hz, CH2Ph), 4.72 (1H, d, J = 11.5 Hz, CH2Ph), 4.75 (1H, d, J = 11.0
Hz, CH₂Ph), 4.79 (1H, d, J = 11.0 Hz, CH₂Ph), 4.94 (1H, dd, J = 7.0, 5.0 Hz, H1), 7.33 (10H, m Ar-H). 

¹³C NMR δ 34.5 (CH₂), 43.8 (CH₂), 61.1 (CH₂), 67.2 (CH), 70.1 (CH), 72.3 (CH₂), 74.5 (CH₂), 76.4 (CH), 76.7 (CH), 77.7 (CH), 128.4-129.0 (10×Ar-CH) 137.0 (Ar-C), 137.8 (Ar-C), 162.9(CO).

(2S,3S)-2-((1R,2S,3S)-2,3-Bis(benzyloxy)-1,4-dihydroxybutyl)-pyrrolidin-3-ol (12) and (2R,3S)-2-((2R,3S,4S)-3,4-bis(benzyloxy)-tetrahydrofuran-2-yl)pyrrolidin-3-ol (13).

Compound 11 (65.4 mg, 0.16 mmol) was dissolved in MeOH (20 mL) and then a solution of NaOH (63.2 mg, 1.58 mmol) in water (5 mL) was added. The mixture was placed in a teflon tube with a 100 bar pressure cap, then heated in a CEM Discover microwave reactor with constant temperature heating at 110 ºC for 2 h. After cooling the mixture was poured into water (50 mL), then extracted with EtOAc (4 x 30 mL). The combined organic extracts were dried (MgSO₄), filtered and evaporated in vacuo to give a semisolid. The pure products were obtained by column chromatography (10:1:0.5; EtOAc: MeOH:NH₄OH), which gave the desired compound 12 (49 mg, 80%, Rᵣ = 0.33, 10:1:0.5 EtOAc:MeOH:NH₄OH), as a clear oil, and product 13 (10 mg, 16%, Rᵣ = 0.44, 10:1:0.5 EtOAc:MeOH:NH₄OH) as a white solid.

12: [α]D²⁷ +32 (c 7.5, CHCl₃). MS (ESI⁺) m/z 388 (M+H⁺, 100%), HRMS (ESI⁺) caled for C₂₂H₃₀NO₅ (M+H⁺) 388.2128, found 388.2128.¹H NMR (CD₃OD) δ 1.69 (1H, m, H4), 1.84 (1H, dd, J = 13.5, 8.0 Hz, H4), 2.71 (1H, dd, J = 7.5, 2.5 Hz, H2), 3.06 (1H, app. dt, J = 10.5, 2.0 Hz, H5), 3.54 (1H, ddd, J = 10.5, 9.5, 8.0 Hz, H5), 3.94 (1H, app. t, J = 2.5 Hz, H3), 4.00 (1H, app. dt, J = 6.0, 2.5 Hz, H3’), 4.21(1H, dd, J = 10.5, 6.0 Hz, H4’), 4.35 (1H, dd, J = 11.0, 5.5 Hz, H4’), 4.52 (1H, dd, J = 9.0, 2.5 Hz, H2’), 4.56 (1H, d, J = 12.0 Hz, CH₂Ph), 4.63 (1H, d, J = 11.0 Hz, CH₂Ph), 4.77 (1H, d, J = 11.5 Hz, CH₂Ph), 4.81 (1H, dd, J = 9.0, 7.5 Hz, H1’), 4.83 (1H, d, J = 10.5 Hz, CH₂Ph), 7.37 (10H, m, Ar-H).

¹³C NMR (CD₃OD) δ 34.8 (CH₂), 43.2 (CH₂), 65.4 (CH), 66.3 (CH₂), 69.4 (CH), 71.5 (CH₂), 74.6 (CH), 74.9 (CH₂), 76.8 (CH), 78.9 (CH),127.8-128.5 (10×Ar-CH), 138.0 (Ar-C), 138.4 (Ar-C).
13: \([\alpha]_D^{28} +21\ (c\ 9.4,\ CHCl_3)\). IR \(\nu_{\text{max}}/\text{cm}^{-1}\) 3450, 3057, 3027, 2930, 2868, 1614, 1454, 1096, 1073. MS (ESI+) \(m/z\ 370\ (M+H^+,\ 100\%).\) HRMS (ESI+) calcd for \(C_{22}H_{28}NO_4\ (M+H^+)\ 370.2135,\) found 370.2130. 1H NMR \(\delta\) 1.81 (1H, m, H4), 1.97 (1H, m, H4), 2.87 (1H, m, H5), 3.05 (1H, app. t, \(J = 5.0\) Hz, H2), 3.21 (1H, m, H5), 3.90 (1H, dd, \(J = 10.5,\ 4.5\) Hz, H5'), 4.08-4.01 (3H, m, H2', H4', H5'), 4.15 (1H, br d, \(J = 5.0\) Hz, H3'), 4.23 (1H, m, H3), 4.50 (1H, d, \(J = 12.5\) Hz, \(CH_2Ph\)), 4.54 (1H, d, \(J = 12.0\) Hz, \(CH_2Ph\)), 4.57 (1H, \(J = 12.0\) Hz, \(CH_2Ph\)), 4.61 (1H, d, \(J = 11.5\) Hz, \(CH_2Ph\)), 7.39 (10H, m, Ar-H). 13C NMR (CDCl3) \(\delta\) 35.4 (CH2, C4), 44.7 (CH2, C5), 65.5 (CH, C2), 71.6 (C4'-OCH2Ph), 72.0 (CH2, C5'), 72.5 (C3'-OCH2Ph), 73.4 (CH, C3), 83.0 (CH, C4'), 83.3 (CH, C2'), 86.1 (CH, C3'), 137.4 (Ar-C), 137.6 (Ar-C).

(1S,6S,7S,8R,8aS)-6,7-Bis(benzyloxy)-octahydroindolizine-1,8-diol (14) and (3aS,6S,7S,8R,8aS)-6,7-bis(benzyloxy)-octahydro-1H-oxepino-[3,2-b]pyrrol-8-ol (15).

To a solution of 12 (49.2 mg, 0.13 mmol) in dry THF (2 mL) was added triphenylphospheine (47 mg, 0.18 mmol) and diisopropyl azodicarboxylate (36 mg, 0.18 mmol) at 0 °C. The mixture was stirred at 0-5 °C for 12 h, then the volatiles were removed \(in\ vacuo\) to give an oil. The pure products were obtained by column chromatography (100% EtOAc and 8.4:1:4:0.2; EtOAc:MeOH:NH4OH), which gave the major compound 14 (11.5 mg, 25%, \(R_t = 0.47,\ 8.4:1:4.0.2\) EtOAc:MeOH:NH4OH) as a clear oil and compound 13 (10 mg, 22% \(R_t = 0.15,\ 8.4:1:4.0.2\) EtOAc:MeOH:NH4OH or \(R_t = 0.44,\ 10:1:0.5\) EtOAc:MeOH:NH4OH), as a white solid, as well as compound 15 (5.0 mg, 11%, \(R_t = 0.27,\ 8.4:1:4.0.2\) EtOAc:MeOH:NH4OH) as a white solid.

14: \([\alpha]_D^{27} +71\ (c\ 2.5,\ CHCl_3)\). IR \(\nu_{\text{max}}/\text{cm}^{-1}\) 3360, 3000, 2940, 2868, 1662, 1091, 1075. MS (ESI+) \(m/z\ 370\ (M+H^+,\ 100\%).\) HRMS (ESI+) calcd for \(C_{22}H_{28}NO_4\ (M+H^+)\ 370.1135,\) found 370.1130. 1H NMR \(\delta\) 1.74 (1H, m, H2), 1.85 (1H, dd, \(J = 10.0,\ 4.5\) Hz, H8a), 1.94 (1H, app. t, \(J = 9.8\) Hz, H5), 2.12 (1H, app. q, \(J = 9.0\) Hz, H3), 2.33 (1H, m, H2), 3.08 (1H, app. dt, \(J = 9.0,\ 2.5\) Hz, H3), 3.29 (1H, dd, \(J = 9.0,\ 5.5\) Hz, H7), 3.34 (1H, app. t, \(J = 9.8\) Hz, H5), 3.62 (1H, m, H6), 3.76 (1H, app. t, \(J = 9.5\) Hz, H8),
4.30 (1H, m, H1), 4.62 (1H, d, J = 11.5 Hz, CH₂Ph), 4.66 (1H, d, J = 11.5 Hz, CH₂Ph), 4.87 (2H, br.s., CH₂Ph), 7.30 (10H, m, Ar-H). ¹³C NMR δ 33.4 (CH₂, C2), 52.0 (CH₂, C3), 54.2 (CH₂, C5), 69.4 (CH, C8), 69.8 (CH, C1), 72.5 (C7-OCH₂Ph), 72.8 (CH, C8a), 75.1 (C6-OCH₂Ph), 78.8 (CH, C8), 87.3 (CH, C7), 127.2-128.1 (10×Ar-CH), 138.4(Ar-C), 138.8(Ar-C).

15: [α]_D^27 + 45 (c 2.3, CHCl₃). IR ν max/cm⁻¹ 3288, 2904, 2842, 1665, 1091, 1075. MS (ESI+) m/z 370 (M+H⁺, 100%). ¹H NMR δ 1.89 (1H, m, overlapped with OH and NH, H3), 1.95 (1H, m, overlapped with OH and NH, H3), 2.93 (1H, m, H2), 3.15 (1H, m, H2), 3.35 (1H, dd, J = 8.8, 3.8 Hz, H8a), 3.83 (1H, dd, J = 9.8, 1.8 Hz, H5), 4.09-4.20 (4H, m, H5, H6, H7, H8), 4.47 (1H, m, H3a), 4.48 (1H, d, J = 12.0 Hz, CH₂Ph), 4.53 (1H, d, J = 12.0 Hz, CH₂Ph), 4.55 (1H, d, J = 11.5 Hz, CH₂Ph), 4.63 (1H, d, J = 11.5 Hz, CH₂Ph), 7.30 (10H, m, Ar-H). ¹³C NMR δ 34.9 (CH₂, C3), 44.9 (CH₂N, C2), 61.5 (CHN, C8), 71.7 (CH₂Ph), 72.2 (CH₂, C5), 72.3 (CH₂Ph), 73.2 (CH, C3a), 80.3 (CH, C8), 81.9 (CH, C7), 82.5 (CH, C6), 127.9-128.8 (10×Ar-CH), 137.9 (Ar-C), 138.0 (Ar-C).

(1S,6S,7R,8R,8aS)-Octahydroindolizine-1,6,7,8-tetraol (castanospermine) (1)
The indolizidine 14 (6.4 mg, 0.173 mmol) was dissolved in methanol (1 mL), then PdCl₂ (2.4 mg, 0.013 mmol) was added. The mixture was stirred under an atmosphere of H₂ (balloon) for 1 h at rt, before the mixture was filtered through a plug of cotton wool. The filtrates were evaporated in vacuo, then the residue was dissolved in water (1 mL) and applied to a column of DOWEX-1-basic ion exchange resin. Elution with water (30 mL) followed by evaporation of the eluent in vacuo gave the title product castanospermine, 1, (3.1 mg, 95%) as a colourless solid. Mp 206-208 °C (lit.¹ 212-215 °C). [α]_D^27 + 82 (c 1.2, H₂O) (lit.¹ [α]_D^24 + 79.7 (c 0.93, H₂O)). R_f 0.18 (96 : 4 EtOH: aqueous NH₃). ESI+ m/z 190 (M+H⁺, 100%). ¹H NMR (D₂O, HOD ref. at 4.79 ppm) δ 1.72 (1H, dddd, J₂β₂α = 14, J₃β₃α = 8.5, J₂β₃β = 8.5, J₂β₁ = 1.8, H2β), 2.03 (1H, dd, J₈a₈ = 10, J₈a₁ = 4.5, H8a), 2.07 (1H, t, J₉β₅α = J₅β₆ = 10.5, H5β), 2.23 (1H, q, J₃β₂β = J₃β₃α = J₃β₂α = 9.5, H3β), 2.35 (1H, dddd, J₂β₂α = 14, J₆α₃β =,
9.5, \( J_{2a,1} = 7.5 \), \( J_{2a,3a} = 2.5 \), \( H2\alpha \), 3.09 (1H, ddd, \( J_{3a,3\beta} = J_{3a,2\beta} = 9 \), \( J_{3a,2a} = 2.5 \), \( H3\alpha \), 3.19 (1H, dd, \( J_{5a,5\beta} = 10.5 \), \( J_{5a,6} = 5 \), \( H5\alpha \), 3.34 (1H, t, \( J_{7,8} = J_{6,7} = 9.5 \), \( H7 \)), 3.61 (1H, t \( J_{8,8a} = J_{8,7} = 9.5 \), \( H8 \)), 3.63 (1H, ddd, \( J_{6,5\beta} = 10.5 \), \( J_{6,7} = 9.5 \), \( J_{6,5a} = 5 \), \( H6 \)), 4.42 (1H, ddd, \( J_{1,2a} = 7 \), \( J_{1,8a} = 4.5 \), \( J_{1,2\beta} = 1.8 \), \( H1 \)). \(^{13}\)C NMR (D_{2}O, internal reference, acetone at 30.89 ppm) \( \delta \) 79.3 (CH, C7), 71.7 (CH, C8a), 70.4 (CH, C6), 69.9 (CH, C1), 69.2 (CH, C6), 55.7 (CH2, C5), 51.8 (CH2, C3), 33.0 (CH2, C2).

References


An alternative mechanism for the formation of 13 from the cyclization 11 (Scheme 2), may involve terminal alkoxide displacement of the carboxylate moiety of the cyclic carbamate. This would produce 2-epi-13. The fact that the same compound 13 is produced in both Schemes 2 and 3 suggests that this alternative mechanism does not occur since the primary hydroxyl in 12 would be expected to be selectively activated under Mitsunobu cyclization conditions. We thank a referee for bringing this to our attention.

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castanospermine and a referee for comments on the mechanism of the formation of 13.

GRAPHICAL ABSTRACT

Synthesis of Castanospermine

Theeraphan Machan, Andrew S. Davis, Boonsom Liawruangrath and Stephen G. Pyne