Supplementary Information

(2R,3R,4E)-3-Benzyl-[(1’R)-1’-phenyl-ethyl]-amino-2-(benzoyl carbonate)-hex-4-enoic acid methyl ester 6

n-Butyllithium (1.38 M, 0.57 mL, 0.79 mmol) was added dropwise to a solution of hexamethyl disilazane (0.18 mL, 0.83 mmol) in THF (1 mL) at 0 °C and stirred for 30 min. The solution was added dropwise via cannula to a solution of the β-amino ester \(^1\) 5 (176 mg, 0.520 mmol) in THF (2 mL) at 0 °C, stirred for 60 min and cooled to −78 °C. Dibenzyl peroxycdicarbonate \(^2\) (157 mg, 0.520 mmol) in THF (1.5 mL) was then added dropwise via cannula and stirring continued at −78 °C for 1.75 h. The mixture was warmed to 0 °C and quenched with saturated ammonium chloride solution (15 mL), water (20 mL) was then added and the mixture extracted with ether (3 × 15 mL) and CH\(_2\)Cl\(_2\) (2 × 15 mL). The combined organic extracts were dried (MgSO\(_4\)) and evaporated under reduced pressure. Purification by flash chromatography, eluting with 95 : 5 petrol−ethyl acetate, gave the β-amino ester \(^6\) (109 mg, 27%) as a colourless oil, R\(_f\) 0.15 (20% EtOAc in petrol); \([\alpha]_{D}^{20} -14.6\) (c. 0.41 in CHCl\(_3\)); \(\nu_{\text{max}}/\text{cm}^{-1}\) (film) 2953, 1751, 1452 and 698; \(\delta_{\text{H}}\) (300 MHz, CDCl\(_3\)) 7.36-7.18 (15 H, m, 3 × Ph), 5.68-5.62 (2 H, m, 4-H and 5-H), 5.09 (2 H, s, PhCH\(_2\)O), 4.98 (1 H, d, J 5.0, 2-H), 4.06 (1 H, q, J 6.8, 1’-H), 3.95 (1 H, d, \(^2\)J, 14.3, PhCH\(_2\)NH), 3.73 (1 H d, \(^2\)J, 14.3, PhCH\(_2\)BN), 3.73 (1 H, dd, J 8.1 and 5.0, 3-H), 3.53 (3 H, s, CO\(_2\)Me), 1.68 (3 H, d, J 5.0, 6-H\(_3\)) and 1.33 (3 H, d, J 6.8, 2’-H\(_3\)); \(\delta_{\text{C}}\) (75 MHz, CDCl\(_3\)) 169.2, 154.9, 144.0, 141.2, 135.4, 131.4, 130.4, 129.5, 129.0, 128.9, 128.9, 128.7, 128.6, 128.5, 128.5, 128.4, 128.3, 127.2, 127.0, 126.7, 79.2, 70.4, 61.4, 57.2, 52.6, 52.4, 18.6 and 14.4; \(m/z\) (ES) 488 (100%, MH\(^+\)), 384 (17) and 338 (9).

(2R, 3S, 5R, 6R)-5,6-Dimethoxy-5,6-dimethyl-[1,4]-dioxane-2-pyrrolidinamide-3-methylcarboxylate 13

Trimethylaluminium (2.0 M in pentanes, 0.61 mL, 1.23 mmol) was added slowly to pyrrolidine (0.10 mL, 1.25 mmol) in toluene (0.45 mL) at room temperature. After stirring for 15 min, the diester \(^3\) 9 (91 mg, 0.311 mmol) was added in one portion. The solution was stirred at room temperature for 96 h, cooled to −78 °C and quenched by the cautious addition of
methanol (0.1 mL). The solid residues were removed by filtration through of Celite and the filtrate evaporated under reduced pressure. Purification by flash chromatography, eluting with 70 : 30 petrol–ethyl acetate followed by neat ethyl acetate, gave the amide3 13 (6.3 mg, 6%) as a pale yellow oil, Rf 0.43 (EtOAc); [α]D20 0 −171 (c. 0.63 in CDCl3); νmax/cm−1 (film) 2952, 1746 and 1622; δH (300 MHz, CDCl3) 4.80 (1 H, d, J 3.9, 2- or 3-H), 4.68 (1 H, d, J 3.9, 3- or 2-H), 4.09 (1 H, dt, 1/2 J 11.2 and J 7.2, NCH3), 3.75 (3 H, s, ester OMe), 3.65 (1 H, dt, 1/2 J 11.2 and J 7.2, NCH3), 3.50 (2 H, t, J 6.9, NCH2), 3.31 (3 H, s, 5- or 6-OMe), 3.22 (3 H, s, 6- or 5-OMe), 2.01-1.86 (2 H, m, NCH2CH2), 1.85-1.73 (2 H, m, NCH2CH2), 1.35 (3 H, s, 5- or 6-Me) and 1.34 (3 H, s, 6- or 5-Me); δC (75 MHz, CDCl3) 170.6, 167.7, 100.8, 99.7, 70.1, 69.7, 52.2, 50.3, 49.0, 47.9, 47.4, 27.2, 23.6, 18.3, and 18.2; m/z (ES) 354 (43%, MNa+), 332 (62, MH+) and 300 (100, M+−OMe).

(2R, 3S, 5R, 6R)-5,6-Dimethoxy-[1,4]-dioxane-3-methylcarboxylate-2-carboxylic acid 10
1,8-Diazabicyclo[5.4.0]undec-7-ene (2.4 mL, 17 mmol) was added to a suspension of the diester3 9 (2.41 g, 8.25 mmol) in water (30 mL) and stirred for 16 h at room temperature. The mixture was adjusted to pH 2 with an aqueous hydrochloric acid solution (2 M), extracted with ethyl acetate (5 × 50 mL), dried (MgSO4) and evaporated under reduced pressure. Purification by flash chromatography, eluting with 97 : 2 : 1 dichloromethane–methanol–acetic acid, gave the mono-acid 10 (1.52 g, 66%) as a colourless foam, Rf 0.36 (4% MeOH in CH2Cl2 + 2% AcOH); [α]D20 0 −130 (c. 1.05 in CDCl3); νmax/cm−1 (film) 3214 (br.), 2953 and 1745; δH (300 MHz, CDCl3) 4.71 (1 H, d, J 4.1, 2- or 3-H), 4.58 (1 H, d, J 4.1, 3- or 2-H), 3.78 (3 H, s, CO2Me), 3.32 (3 H, s, 5- or 6-OMe), 3.24 (3 H s, 6- or 5-OMe), 1.41 (3 H, s, 5- or 6-Me) and 1.36 (3 H, s, 6- or 5-Me); δC (75 MHz, CDCl3) 170.5, 169.9, 101.6, 99.9, 69.2, 66.7, 52.6, 50.6, 49.2, 18.3 and 17.9; m/z (ES) 301 (67%, MNa+) and 247 (45, M+−OMe). (Found: MNa+, 301.0916. C11H18O8 requires MNa, 301.0899).

(2R, 3S, 5R, 6R)-5,6-Dimethoxy-[1,4]-dioxane-3-methylcarboxylate-2-dipropylamide 11
1-[3-(Dimethylamino)propyl]-3-ethyl carbodiimide hydrochloride (1.24 g, 6.50 mmol) was added to a solution of 1-hydroxybenztriazole hydrate (0.88 g, 6.50 mmol), dipropylamine
(0.90 mL, 6.5 mmol) and the acid 10 (1.50 g, 5.40 mmol) in ethyl acetate (85 mL) and the solution stirred for 18 h at room temperature. Water (100 mL) and ethyl acetate (100 mL) were added, the organic layer separated and the aqueous layer extracted with ethyl acetate (3 × 75 mL), the combined organic extracts were dried (MgSO₄) and evaporated under reduced pressure. Purification by flash chromatography, eluting with 80 : 20 petrol–ethyl acetate, gave the amide 11 (1.40 g, 72%) as a colourless oil which crystallised on standing to colourless needles, m.p. 56.8-59.0 °C (from Et₂O–petrol); \( R_f 0.12 \) (20% EtOAc in petrol); \( \left[ \alpha \right]_{D}^{20} -107 \) (c. 1.07 in CHCl₃); (Found: C, 56.5; H, 8.70; N, 3.7; \( \text{C}_{17}\text{H}_{31}\text{NO}_{7} \) requires: C, 56.5; H, 8.65; N, 3.9); \( \nu_{\max}/\text{cm}^{-1} \) (film) 2961, 1747 and 1625; \( \delta_{\text{H}} \) (500 MHz, CDCl₃) 4.85 (1 H, d, \( J \) 4.0, 2-H), 4.71 (1 H, d, \( J \) 4.0, 3-H), 3.86 (1 H, ddd, \( J \) 14.1, \( J \) 10.7 and 5.5, NCA\( \text{H}_{A} \)), 3.73 (3 H, s, CO₂Me), 3.41 (1 H, dt, \( J \) 13.2 and \( J \) 7.7, NC₈H₄), 3.31 (3 H, s, 6-OME), 3.26 (1 H, ddd, \( J \) 14.1, \( J \) 10.7 and 5.5, NC₈H₄), 3.22 (3 H, s, 5-OME), 3.04 (1 H, dt, \( J \) 13.2 and \( J \) 7.7, NC₈H₄), 1.80-1.69 (2 H, m, NCH₂CH₂), 1.68-1.57 (2 H, m, NCH₂CH₂), 1.33 (3 H, s, 5-Me), 0.91 (3 H, t, \( J \) 7.7, CH₂CH₃) and 0.88 (3 H, t, \( J \) 7.7, CH₂CH₃); \( \delta_{\text{C}} \) (75 MHz, CDCl₃) 170.5, 168.3, 100.8, 99.6, 70.2, 70.2, 52.1, 50.2, 49.9, 49.8, 49.2, 23.4, 20.8, 18.4, 18.3, 11.9 and 11.56; \( m/z \) (ES) 384 (16%, MNa⁺), 362 (83, MH⁺) and 330 (100, M⁺–OME). (Found: MNa⁺, 384.1996. \( \text{C}_{17}\text{H}_{31}\text{NO}_{7} \) requires MNa⁺, 384.1998).

Also obtained was (2\( R \), 3\( R \), 5\( R \), 6\( R \))-5,6-Dimethoxy-[1,4]-dioxane-3-methylcarboxylate-2-dipropylamide 16 (76 mg, 4%) as a colourless oil, \( R_f 0.42 \) (20% EtOAc in petrol); \( \left[ \alpha \right]_{D}^{20} -61.3 \) (c. 2.20 in CH₂Cl₂); \( \nu_{\max}/\text{cm}^{-1} \) (film) 2927, 1745 and 1650; \( \delta_{\text{H}} \) (500 MHz, CDCl₃) 4.99 (1 H, d, \( J \) 10.1, 2- or 3-H), 4.96 (1 H, d, \( J \) 10.1, 3- or 2-H), 3.74 (3 H, s, CO₂Me), 3.38-3.23 (4 H, m, 2 × NCH₂) 3.35 (3 H, s, 5- or 6-OME), 3.31 (3 H, s, 6- or 5-OME), 1.66 (2 H, m, NCH₂CH₂), 1.55 (2 H, m, NCH₂CH₂), 1.41 (3 H, m, 5- or 6-Me), 1.37 (3 H, m, 5- or 6-Me), 0.94 (3 H, t, \( J \) 7.4, CH₂CH₃) and 0.87 (3 H, t, \( J \) 7.4, CH₂CH₃); \( \delta_{\text{C}} \) (75 MHz, CDCl₃) 170.4, 168.1, 101.3, 101.1, 71.6, 68.8, 52.7, 49.6, 49.1, 49.1, 47.8, 30.1, 22.8, 21.1, 18.5, 11.7 and 11.6; \( m/z \) (ES) 362 (56%, MH⁺) and 330 (100, M⁺–OME). (Found: MNa⁺ 384.2002. \( \text{C}_{17}\text{H}_{31}\text{NO}_{7} \) requires MNa⁺, 384.1998).

\( (2\( R \), 3\( R \), 5\( R \), 6\( R \))-5,6-Dimethoxy-[1,4]-dioxane-2,3-bis(dipropylamide) 15 \)
Lithium hydroxide (286 mg, 6.80 mmol) was added to a solution of the diester 9 (200 mg, 0.68 mmol) and hydrogen peroxide (30% in water, 1.50 L, 13.6 mmol) in tetrahydrafuran–water (3 : 1, 3 mL) at 0 °C. The solution was warmed to room temperature, stirred for 3 days, quenched with an aqueous sodium thiosulfate solution (1.5 M, 10 mL), adjusted to pH 2 with dilute aqueous hydrochloric acid, extracted with ethyl acetate (3 × 25 mL) dried (MgSO4) and evaporated under reduced pressure. The residue was redissolved in ethyl acetate (10 mL) cooled to 0 °C, dipropylamine (123 µL, 0.90 mmol), 1-hydroxybenzatriazole hydrate (135 mg, 0.90 mmol) and 1-[3-(Dimethylamino)propyl]-3-ethyl carbodiimide hydrochloride (173 mg, 0.90) were added, the mixture was warmed to room temperature and stirred for 20 h. Water (15 mL) and ethyl acetate (10 mL) were added, the organic layer separated, the aqueous layer extracted with ethyl acetate (2 × 20 mL), the combined organic extracts were dried (MgSO4) and evaporated under reduced pressure. Purification by flash chromatography, eluting with 90 : 10 petrol–ethyl acetate, gave the diamide 15 (17 mg, 6%) as a colourless oil, Rf 0.48 (30% EtOAC in petrol); [α]D20 −63.8 (c. 0.79 in CHCl3); νmax/cm−1 (film) 2964 and 1650; δH (500 MHz, CDCl3) 5.09 (2 H, s, 2- and 3-H), 3.38-3.15 (8 H, m, 4 × NC2H5), 3.33 (6 H, s, 5- and 6-OMe), 1.76-1.63 (4 H, m, 2 × NCH2CH3), 1.59-1.43 (4 H, m, 2 × NCH2CH3), 1.40 (6 H, s, 5- and 6-Me), 0.94 (6 H, t, J 7.4, CH2CH3) and 0.85 (6 H, t, J 7.4, CH2CH3); δC (75 MHz, CDCl3) 168.4, 101.1, 69.3, 49.6, 49.0, 47.7, 22.8, 21.1, 17.83, 11.8 and 11.6; m/z (ES) 431 (50, MH+) and 399 (100, M+–OMe). (Found: M+–OMe, 399.2845. C22H42NO6 requires M−OMe, 399.2859).

(2R, 3S)-1-Dipropylamide-4-methylcarboxylate-2,3-hydroxy-butane 12

A trifluoroacetic acid–water solution (9 : 1, 5 mL) was added to the diacetal 11 (200 mg, 0.55 mmol) and the resulting mixture swirled for 2 min at room temperature and evaporated under reduced pressure. Purification by flash chromatography, eluting with 50 : 50 petrol–ethyl acetate, to give the amide 12 (105 mg, 77%) as a colourless oil; Rf 0.18 (50% EtOAc in petrol); [α]D20 +60.3 (c. 1.24 in CHCl3); νmax/cm−1 (film) 3391, 2964, 2877, 1748 and 1633; δH (500 MHz, CDCl3) 4.64 (1 H, d, J 3.2, 2- or 3-H), 4.34 (1 H, d, J 3.2, 3- or 2-H), 3.74 (3 H, s, CO2Me), 3.50 (1 H, dt, 2J 13.7 and J 7.7, NCH2), 3.33 (1 H, dt, 2J 15.0 and J 7.7 NCH2), 3.26
(1 H, dt, $^2J$ 15.0 and $J$ 7.7, NCH$_2$), 3.12 (1 H, dt, $^2J$ 13.7 and $J$ 7.7, NCH$_2$), 1.65 (2 H, sx, $J$ 7.7, NCH$_2$CH$_2$), 1.58 (2 H, sx, $J$ 7.7, NCH$_2$CH$_2$), 0.95 (3 H, t, $J$ 7.7, CH$_2$CH$_3$) and 0.91 (3 H, t, $J$ 7.7, CH$_2$CH$_3$); $\delta_C$ (75 MHz, CDCl$_3$) 171.8, 170.5, 73.1, 70.4, 52.8, 49.3, 48.2, 22.4, 20.9, 11.7 and 11.5; $m/z$ (ES) 248 (100%, MH$^+$). (Found: MH$^+$, 248.1495. C$_{11}$H$_{21}$NO$_5$ requires MH$^+$, 248.1498).

(2R, 3R)-N,N-Dimethyl-2,3-O-isopropylidene-4-hydroxybutyramide 23a

Dimethylamine (2 M in MeOH, 20 mL, 40 mmol) was added slowly to the lactone$^4$ 22 (2.50 g, 15.8 mmol) at 0 °C under N$_2$. The resulting solution was stirred for 15 min, allowed to warm to room temperature, stirred for a further 1 h and evaporated under reduced pressure. Purification by flash chromatography, eluting with 95 : 5 ethyl acetate–methanol, and recrystallisation from petrol–diethyl ether gave the amide 23a (2.85 g, 89%), as colourless needles, m.p. 69.2-72.4 °C (from petrol–Et$_2$O); $R_f$ 0.08 (EtOAc); $[\alpha]_{D}^{20}$ +33.5 (c. 1.42 in CDCl$_3$); (Found: C, 53.3; H, 8.30; N, 6.8; C$_9$H$_{17}$NO$_4$ requires: C, 53.2; H, 8.45; N, 6.9); $\nu_{\text{max}}$/cm$^{-1}$ (film) 3400, 2937 and 1652; $\delta_H$ (500 MHz, CDCl$_3$) 4.93 (1 H, d, $^2J$ 6.1, 2-H), 4.40 (1 H, q, $^3J$ 6.1, 3-H), 3.72 (1 H, dt, $^2J$ 12.3 and $J$ 6.1, 4-H$_A$), 3.58 (1 H, dt, $^2J$ 12.3 and $J$ 6.1, 4-H$_B$), 3.39 (1 H, t, $J$ 6.1, OH), 3.12 (3 H, s, NMe), 2.99 (3 H, s, NMe), 1.56 (3 H, s, CMe) and 1.40 (3 H, s, CMe); $\delta_C$ (75 MHz, CDCl$_3$) 168.5, 110.0, 78.2, 75.5, 62.7, 37.6, 36.6, 27.7 and 25.9; $m/z$ (ES) 226 (63 %, MNa$^+$) and 204 (35, MH$^+$).

(2R, 3R)-N,N-Dipropyl-2,3-O-isopropylidene-4-hydroxybutyramide 23b

Dipropylamine (47 mL, 340 mmol) in methanol (123 mL) was added slowly to the lactone 22 (5.38 g, 34.0 mmol) at 0 °C under N$_2$, the resulting solution allowed to warm to room temperature and stirred at room temperature for 72 h. Toluene (120 mL) was added and the mixture evaporated under reduced pressure. Purification by flash chromatography, eluting with 70 : 30 petrol–ethyl acetate, and recrystallisation from petrol–diethyl ether gave the amide 23b (5.76 g, 65%) as colourless needles, m.p. 64.1-67.8 °C (from petrol–Et$_2$O); $R_f$ 0.41 (50% EtOAc in petrol); $[\alpha]_{D}^{20}$ +18.8 (c. 1.45 in CDCl$_3$); (Found: C, 60.3; H, 9.60; N, 5.2; C$_{13}$H$_{25}$NO$_4$ requires: C, 60.2; H, 9.75; N, 5.4); $\nu_{\text{max}}$/cm$^{-1}$ (film) 3400, 2937 and 1647; $\delta_H$ (500
MHz, CDCl₃) 4.89 (1 H, d, $J = 6.2$, 2-H), 4.37 (1 H, dt, $J = 10.2$ and 6.2, 3-H), 3.74-3.67 (1 H, m, 4-Hₐ), 3.60-3.54 (1 H, m, 4-Hₐ), 3.39-3.20 (5 H, m, 2 × NCH₂ and OH), 1.67-1.54 (4 H, m, 2 × NCH₂CH₂), 1.57 (3 H, s, Me), 1.40 (3 H, s, Me), 0.93 (3 H, t, $J = 7.4$, NCH₂CH₂CH₃) and 0.91 (3 H, t, $J = 7.4$, NCH₂CH₂CH₃); δC (75 MHz, CDCl₃) 168.2, 110.2, 78.5, 75.3, 62.9, 50.0, 49.0, 27.5, 25.9, 22.9, 21.0, 11.8 and 11.6; m/z (ES) 282 (28 %, MNa⁺) and 260 (64, MH⁺).

(4R,5R, 6R)- and (4S,5R, 6R)-6-Dipropylcarbamoyl-2-methylidene-4-hydroxy-5,6-0-isopropylidene-hexanoic acid ethyl ester 25 and 26

Oxalyl chloride (3.7 mL, 43 mmol) was added slowly to a stirred solution of dimethyl sulfoxide (6.1 mL, 86 mmol) in dichloromethane (170 mL) under N₂ at −78 °C and the resulting solution stirred for 45 min at −78 °C. A solution of the alcohol 23b (5.56 g, 21.5 mmol) in dichloromethane (125 mL) was added dropwise via cannula and the mixture stirred for 3.5 h at −78 °C. Triethylamine (48 mL, 344 mmol) was added and the solution allowed to warm to room temperature over 1 h. Water (300 mL) was added, the organic layer separated and the aqueous layer extracted with dichloromethane (2 × 300 mL). The combined organic extracts were washed with brine (500 mL), dried (MgSO₄) and evaporated under reduced pressure to give the crude aldehyde which was used immediately without purification. To the crude aldehyde in tetrahydrafuran–water (1 : 1, 300 mL) was added indium powder (2.72 g, 23.7 mmol) and ethyl α–(bromomethyl)acrylate⁵ (3.6 mL, 26 mmol), the resulting suspension was stirred for 40 h at room temperature and filtered through Celite. Ethyl acetate (150 mL) was added, the organic layer separated and the aqueous layer extracted with ethyl acetate (2 × 150 mL). The combined organic extracts were washed with brine (300 mL), dried (MgSO₄) and evaporated under reduced pressure. Purification by column chromatography (gradient elution : 20% → 45% EtOAc in Petrol) and recrystallisation from petrol–diethyl ether) gave the (4R)-amide 25 (3.57 g, 45%) as colourless plates, m.p. 54.7-57.5 °C (from petrol–Et₂O); $R_f$ 0.45 (50% EtOAc in petrol); $[\alpha]^{20}_{D} +52.2$ (c. 1.64 in CHCl₃); (Found: C, 61.3; H, 8.90; N, 4.0; C₁₉H₃₃NO₆ requires: C, 61.4; H, 8.95; N, 3.8); $\nu_{max}$/cm⁻¹ (film) 3367, 2963, 1710 and 1639; δH (500 MHz, CDCl₃) 6.26 (1 H, s, C=CH₃), 5.73 (1 H, s, C=CH₃), 4.88 (1 H, d, $J = 6.1$, 6-H), 4.21 (2 H, q, $J = 7.1$ OCH₂CH₃), 4.07 (1 H, dd, $J = 8.1$ and 6.1, 5-H), 3.96-3.91 (1 H, m, 4-
H), 3.74 (1 H, d, \(J 4.2\), OH), 3.44-3.34 (2 H, m, NCH\(_2\)), 3.19-3.09 (2 H, m, NCH\(_2\)), 2.87 (1 H, dd, \(2J 14.3\) and \(J 2.0\), 3-H\(\alpha\)), 2.34 (1 H, dd, \(2J 14.3\) and \(J 8.7\), 3-H\(\beta\)), 1.66-1.53 (4 H, m, 2 × NCH\(_2\)CH\(_2\)), 1.60 (3 H, s, CMe), 1.38 (3 H, s, CMe), 1.30 (3 H, t, \(J 7.1\), OCH\(_2\)CH\(_3\)), 0.92 (3 H, t, J 7.4, NCH\(_2\)CH\(_2\)CH\(_3\) and 0.88 (3 H, t, J 7.4, NCH\(_2\)CH\(_2\)CH\(_3\)); \(\delta\)\(_C\) (75 MHz, CDCl\(_3\)) 168.8, 168.6, 137.5, 128.6, 110.3, 80.8, 74.8, 69.4, 61.5, 50.0, 49.0, 37.0, 27.5, 26.2, 22.9, 21.0, 14.6, 11.8 and 11.7; \(m/z\) (ES) 394 (20%, M\(\text{Na}^+\)) and 372 (100, MH\(^+\)).

Also obtained by column chromatography (gradient elution: 5% → 20% EtOAc in Petrol) of the supernatant was the (4S)-amide 26 (1.00 g, 13%) as a colourless oil, \(R_f\) 0.53 (50% EtOAc in petrol); \(\left[\alpha\right]_{D}^{20} +17.2\) (c. 6.82 in CHCl\(_3\)); \(v_{\text{max}}/\text{cm}^{-1}\) (film) 3408, 2967, 1715 and 1639; \(\delta\)\(_H\) (500 MHz, CDCl\(_3\)) 6.25 (1 H, d, \(2J 1.0\), C=CH\(_A\)), 5.73 (1 H, d, \(2J 1.0\), C=CH\(_B\)), 4.92 (1 H, d, J 6.7, 6-H), 4.18 (3 H, m, CO\(_2\)CH\(_2\) and 5-H), 4.00 (1 H, d, J 2.6, OH), 3.72 (1 H, ddd, J 7.7, 5.4, 2.6 and 1.5, 4-H), 3.42 (1 H, ddd, \(2J 13.8\), J 13.3 and 7.7, NCH\(_A\)), 3.30-3.18 (3 H, m, NCH\(_2\) and CH\(_B\)), 2.59 (1 H, ddd, \(2J 14.3\) and J 7.7, 3-H\(\alpha\)), 2.50 (1 H, ddd, \(2J 14.3\) and J 5.4, 3-H\(\beta\)), 1.69-1.52 (4 H, m, NCH\(_2\)CH\(_2\)), 1.67 (3 H, s, CMe), 1.40 (3 H, s, CMe), 1.29 (3 H, t, J 7.1, OCH\(_2\)CH\(_3\)), 0.94 (3 H, t, J 7.3, NCH\(_2\)CH\(_2\)CH\(_3\)) and 0.90 (3 H, t, J 7.5, NCH\(_2\)CH\(_2\)CH\(_3\)); \(\delta\)\(_C\) (75 MHz, CDCl\(_3\)) 168.7, 167.6, 137.5, 128.0, 110.8, 79.7, 74.7, 69.3, 61.0, 49.9, 49.1, 36.8, 26.5, 26.2, 22.9, 21.0, 14.6, 11.8 and 11.6; \(m/z\) (ES) 394 (17%, M\(\text{Na}^+\)) and 372 (100, MH\(^+\)).

(Found: M\(\text{Na}^+\), 394.2202. C\(_{19}\)H\(_{33}\)NO\(_6\) requires \(M\text{Na}\), 394.2206).

\((2R, 3R)\)-\(N, N\)-Dipropyl-2,3,4-trihydroxybutyramide 21b

A solution of trifluoroacetic acid–water (9 : 1, 25 mL) was added to the amide 23b (759 mg, 2.93 mmol), the mixture swirled for 2 min and evaporated under reduced pressure.

Purification by flash chromatography, eluting with 96 : 4 dichloromethane–methanol containing a small amount of triethylamine, followed by recrystallisation from ethyl acetate–petrol, gave the amide 21b (424 mg, 66%) as colourless needles, m.p. 100.4-102.7 °C (from petrol–EtOAc); \(R_f\) 0.50 (10% MeOH in CH\(_2\)Cl\(_2\)); \(\left[\alpha\right]_{D}^{20} -39.2\) (c. 1.02 in MeOH); \(v_{\text{max}}/\text{cm}^{-1}\) (film) 3307, 2955, 2875, and 1617; \(\delta\)\(_H\) (500 MHz, d\(_4\)-MeOD) 4.45 (1 H, d, J 6.3, 2-H), 3.77-3.70 (3 H, m, 3-H, 4-H\(\alpha\) and 4-H\(\beta\)), 3.58 (1 H, ddd, \(2J 15.4\), J 9.8 and 6.3, NCH\(_A\)), 3.49 (1 H, ddd, \(2J 15.0\), J 8.7 and 6.5, NCH\(_A\)), 3.27-3.18 (2 H, m, 2 × NCH\(_B\)), 1.73-1.59 (4 H,
m, 2 × NCH2CH3), 0.97 (3 H, t, J 7.4, CH2CH3) and 0.94 (3 H, t, J 7.5, CH2CH3); δC (75 MHz, d4-MeOD) 175.0, 75.0, 69.5, 64.4, 50.8, 49.6, 23.7, 22.1, 12.0 and 11.7; m/z (ES) 220 (100, MH+). (Found: MH+, 220.1547. C10H21NO4 requires MH, 220.1549).

(2R, 2’R, 3’R)-2’-Hydroxy-2-(3’-hydroxy-5’-oxo-tetrahydro-furan-2’-yl)-N,N-dipropyl-acetamide 49

A solution of the amide 25 (371 mg, 1.00 mmol) in methanol (25 mL) was subjected to ozonolysis at −78°C. Following addition of hydrogen peroxide (30% in water, 2.5 mL), water (5 mL) and formic acid (1 mL), the solution was warmed to room temperature stirred for 3 h and evaporated under reduced pressure. The residue was redissolved in formic acid–water (1: 1, 20 mL), stirred for 18 h and evaporated under reduced pressure. Column chromatography (gradient elution : 50 → 70% ethyl acetate in petrol) gave a crude product which was redissolved in methanol–water (1: 5, 15 mL), barium hydroxide monohydrate (52 mg, 0.274 mmol) was added, the solution stirred for 21 h and evaporated under reduced pressure. The residue was redissolved in water (10 mL), ammonium sulphate (36 mg, 0.274 mmol) was added, the solution stirred for 2 h, passed through a 4 µm filter and evaporated under reduced pressure. The residue was partitioned between ethyl acetate (20 mL) and water (20 mL), the organic layer separated and the aqueous layer extracted with ethyl acetate (3 × 20 mL). The combined organic layers were dried (MgSO4) and evaporated under reduced pressure to give the lactone 49 (68 mg, 26%) as a colourless oil, Rt 0.69 (EtOAc); [α]D 20 +0.9 (c. 1.35 in MeOH); νmax/cm−1 (film) 3391, 2966, 1783, 1631 and 1360; δH (500 MHz, CDCl3) 4.59 (2 H, m, 2-H and 3’-H), 4.29 (1 H, t, J 3.5, 2’-H), 3.47-3.06 (4 H, m, 2 × NCCH2), 2.87 (1 H, dd, 2J 18.0 and J 7.7, 4’-Hα), 2.50 (1 H, dd, 2J 18.0 and J 5.2, 4’-Hβ), 1.61-1.48 (4 H, m, 2 × NCH2CH2), 0.88 (3 H, t, J 7.3, NCH2CH2CH3) and 0.83 (3 H, t, J 7.4, NCH2CH2CH3); δC (75 MHz, CDCl3) 175.2, 170.4, 87.2, 68.7, 67.7, 49.5, 48.3, 38.1, 22.4, 21.0, 11.7 and 11.5; m/z (ES) 260 (100%, MH+). (Found: MH+, 260.1487. C12H21NO5 requires MH, 260.1487).

(2R, 3R)-2,3-O-Isopropylidene-pent-4-enoic acid dipropylamide 35
Oxalyl chloride (120 µL, 1.40 mmol) was added slowly to a stirred solution of dimethyl sulfoxide (200 µL, 2.80 mmol) in dichloromethane (5 mL) under N₂ at −78 °C and the resulting solution stirred for 35 min at −78 °C. A solution of the alcohol 23b (200 mg, 0.77 mmol) in dichloromethane (4 mL) was added dropwise via cannula and the mixture stirred for 3 h at −78 °C. Triethylamine (48 mL, 344 mmol) was added and the solution allowed to warm to room temperature over 1 h. Water (10 mL) was added, the organic layer separated and the aqueous layer extracted with dichloromethane (2 × 15 mL). The combined organic extracts were washed with brine (30 mL), dried (MgSO₄) and evaporated under reduced pressure to give the crude aldehyde. n-Butyllithium (1.43 M in hexane, 1.15 mL, 1.64 mmol) was added slowly to a solution of methyl triphenylphosphonium bromide (607 mg, 1.70 mmol) in tetrahydrafuran (4 mL) at −12 °C. The solution was warmed to room temperature, stirred for 30 min, cooling to −12 °C, the crude aldehyde in tetrahydrafuran (2 mL) was added dropwise via cannula, the mixture warmed to room temperature and stirred for 18 h. The reaction was quenched by addition of a saturated aqueous ammonium chloride solution (10 mL), extracted with diethyl ether (3 × 15 mL). The combined organic extracts were washed with saturated aqueous ammonium chloride solution (20 mL), water (20 mL), dried (MgSO₄) and evaporated under reduced pressure. Purification by flash chromatography, eluting with 85:15 petrol–ethyl acetate, gave the amide 35 (33 mg, 16%) as a colourless oil, Rᵣ 0.42 (40% EtOAc in petrol); [α]D²⁰ −28.6 (c. 0.91 in CHCl₃); νmax/cm⁻¹ (film) 2965, 2875, 1660 and 1455; δH (500 MHz, CDCl₃) 5.80 (1 H, ddd, J 17.1, 10.3 and 7.7, 4-H), 5.40 (1 H, d, J 17.1, 5-Htrans), 5.24 (1 H, d, J 10.3, 5-Hcis), 4.94 (1 H, d, J 7.7, 2-H), 4.78 (1 H, t, J 7.7, 3-H), 3.49 (1 H, dt, J 13.3 and J 7.7, NC₃H), 3.15-3.00 (3 H, m, 3 × NCH₂), 1.66 (3 H, s, CMe), 1.65-1.47 (4 H, m, 2 × NCH₂CH₃), 1.41 (3 H, s, CMe), 0.91 (3 H, t, J 7.3, CH₃CH₃) and 0.88 (3 H, t, J 7.3, CH₂CH₃); δC (75 MHz, CDCl₃) 167.9, 134.2, 120.2, 111.1, 79.8, 76.1, 49.4, 48.6, 27.3, 25.9, 22.6, 21.1, 11.9 and 11.6; m/z (ES) 256 (100%, MH⁺). (Found: MH⁺, 256.1903. C₁₄H₂₅NO₃ requires MH+, 256.1913).
(4R, 3R, 2S)-2’-(3,4-O-Isopropylidene-5-oxo-tetrahydro-furan-2-ylmethyl)-acrylic acid ethyl ester 27 and (2R, 3R, 2’S)-2,3-O-Isopropylidene-3-(4’-methylene-5’-oxo-tetrahydro-furan-2’-yl)-N,N-dipropyl-propionamide 28

In a separate experiment on a 4.86 mmol scale, the crude product was purified by preparative HPLC to give the (4R)-amide 25 (676 mg, 37%) spectroscopically identically to that obtained previously. Further purification by column chromatography (gradient elution: 20% → 35% EtOAc in Petrol) gave the (4S)-amide 26 (202 mg, 3%) as a colourless oil, spectroscopically identical to that obtained previously.

Also obtained was the lactone 27 (173 mg, 3%) as a colourless oil, \( R_f \) 0.35 (50% EtOAc in petrol); \( \alpha \)\(_D\)^20 +93.5 (c. 4.9 in CHCl_3); \( \nu_{\text{max}}/\text{cm}^{-1} \) (film) 2966, 1765, 1650, 1622 and 1465; \( \delta \)H (500 MHz, CDCl_3) 6.19 (1 H, t, \( \text{J} \) 2.6, C=C\(_A\)), 5.60 (1 H, d, \( \text{J} \) 7.7 and 3.1, 2’-H), 4.96 (1 H, d, \( \text{J} \) 7.7 and 3.1, 3-H), 3.75 (1 H, ddd, \( \text{J} \) 14.8, J 10.4 and 5.6, NCH\(_A\)), 3.46 (1 H, dt, \( \text{J} \) 13.3 and J 7.7, NCH\(_A\)), 3.25 (1 H, ddd, \( \text{J} \) 14.3, J 10.4 and 5.6, NCH\(_B\)), 3.09 (1 H, dt, \( \text{J} \) 13.3 and J 7.7, NCH\(_B\)), 2.96 (1 H, ddt, \( \text{J} \) 17.2, J 8.7 and \( \text{J} \) 2.6, 3’-H\(_A\)), 2.82 (1 H, ddt, \( \text{J} \) 17.2, J 5.1 and \( \text{J} \) 2.6, 3’-H\(_B\)), 1.75-1.54 (4 H, m, NCH\(_2\)CH\(_2\)), 1.47 (3 H, s, CMe), 1.36 (3 H, s, CMe), 0.91 (3 H, t, J 6.6, NCH\(_2\)CH\(_2\)CH\(_3\)) and 0.90 (3 H, t, J 6.9, NCH\(_2\)CH\(_2\)CH\(_3\)) \( \delta \)C (75 MHz, CDCl_3) 170.5, 167.6, 134.7, 121.7, 110.9, 80.2, 76.9, 74.9, 49.9, 49.8, 30.2, 26.6, 25.1, 23.1, 20.9, 11.8, and 11.5; m/z (ES) 326 (100, MH+). (Found: MH+, 326.1981; C\(_{17}\)H\(_{27}\)NO\(_5\) requires MH, 326.1967).

Also obtained was the lactone 28 (142 mg, 3%) as a colourless oil, \( R_f \) 0.67 (50% EtOAc in petrol); \( \alpha \)\(_D\)^20 -78.1 (c. 1.25 in CHCl_3); \( \nu_{\text{max}}/\text{cm}^{-1} \) (film) 2988, 1788 and 1713; \( \delta \)H (500 MHz, CDCl_3) 6.35 (1 H, d, \( \text{J} \) 0.8, C=CH\(_A\)), 5.83 (1 H, d, \( \text{J} \) 0.8, C=CH\(_B\)), 4.81 (1 H, d, J 4.6, 4-H), 4.74 (2 H, m, 3- and 2-H), 4.23 (2 H, q, J 7.1, CO\(_2\)CH\(_2\)), 2.89 (1 H, d, \( \text{J} \) 14.5 and J 5.6, 4’-H\(_A\)), 2.81 (1 H, dd, \( \text{J} \) 14.5 and J 7.7, 4’-H\(_B\)), 1.50 (3 H, s, CMe), 1.40 (1 H, s, CMe) and 1.32 (3 H, t, J 7.1, OCH\(_2\)CH\(_3\)) \( \delta \)C (75 MHz, CDCl_3) 173.8, 166.6, 134.7, 129.4, 114.1, 77.4, 76.8, 76.4, 61.1, 32.3, 26.9, 26.0 and 14.2; m/z (ES) 288 (32, MNH\(_4\)^+) and 271 (100, MH+). (Found: MH+, 271.1182; C\(_{13}\)H\(_{18}\)O\(_5\) requires MH, 271.1182).
(4R, 5R, 6R)-6-Dipropylcarbamoyl-2-oxo-4-hydroxy-5,6-O-isopropylidene-hexanoic acid ethyl ester 40

The ester 25 (508 mg, 1.37 mmol) in methanol (40 mL) was divided into ten equal portions and O2 (4 min), O3 (4 min) then O2 (4 min) bubbled through the solutions at −78 °C. Dimethyl sulfide (0.8 mL / portion) was added and the solutions warmed to room temperature, stirred for 4 h, all the portions recombined and evaporated under reduced pressure. Water (30 mL) was added and extracted with ethyl acetate (3 x 50 mL), the combined organic extracts were washed with brine (75 mL), dried (MgSO4) and evaporated under reduced pressure.

Purification by flash chromatography, eluting with 50 : 50 ethyl acetate–petrol, gave the ketone 40 (412 mg, 81%) as a pale yellow oil, \( R_f 0.36 \) (40% EtOAc in petrol); \( [\alpha]_D^{20} +15.8 \) (c. 1.37 in CDCl3); \( \nu_{\text{max}} / \text{cm}^{-1} \) (film) 3391, 2966, 1780, 1728 and 1642; \( \delta_{\text{H}} \) (500 MHz, CDCl3) 4.90 (1 H, d, \( J = 6.3 \), 6-H), 4.37 (1 H, app. tt, \( J = 8.7 \) and 3.9, 4-H), 4.32 (2 H, q, \( J = 7.1 \) OCH2CH3), 4.14 (1 H, dd, \( J = 8.7 \) and 6.3, 5-H), 3.94 (1 H, d, \( J = 3.9 \), OH), 3.42-3.16 (4 H, m, 2 x NC2H), 3.28 (1 H, dd, \( 2J = 16.9 \) and J 3, 3-HA), 2.97 (1 H, dd, \( 2J = 16.9 \) and J 8.6, 3-Hb), 1.67-1.56 (4 H, m, 2 x NCH2CH2), 1.51 (3 H, s, CMe), 1.37 (3 H, t, J 7.1, OCH2CH3), 1.36 (3 H, s, CMe), 0.93 (3 H, t, J 7.5, NCH2CH2CH3) and 0.91 (3 H, t, J 7.5, NCH2CH2CH3); \( \delta_{\text{C}} \) (75 MHz, CDCl3) 193.8, 168.2, 161.2, 110.3, 80.4, 75.1, 67.1, 62.9, 50.1, 49.2, 43.9, 27.4, 25.7, 22.9, 21.0, 14.4, 11.8, and 11.6; \( m/z \) (ES) 747 (24, [2M]+), 406 (90, [M+MeOH]+) and 374 (100, MH%). (Found: MH+ 374.2176. C18H31NO7 requires MH+, 374.2179).

(4R, 5R, 6R)-6-Dipropylcarbamoyl-2-oxo-4,5,6-trihydroxy-hexanoic acid ethyl ester 41

The amide 40 (49 mg, 0.130 mmol) was treated with trifluoroacetic acid–water (1 : 1, 2.0 mL), the mixture stirred for 19 h and evaporated under reduced pressure. Purification by column chromatography (gradient elution: 30%–70% EtOAc in petrol) gave the amide 41 (22 mg, 51%) as a colourless oil, \( R_f 0.39 \) (EtOAc); \( [\alpha]_D^{20} -8.6 \) (c. 0.42 in CHCl3); \( \nu_{\text{max}} / \text{cm}^{-1} \) (film) 3368, 2966, 1745 and 1630; \( \delta_{\text{H}} \) (500 MHz, CDCl3) 4.74-4.66 (1 Hfur(maj) and 1 Hpyr, m, 4-Hfur(maj) and 5-Hpyr), 4.62-4.58 (1 Hfur(maj) and 1 Hfur(min), m, 6-Hfur(maj) and 4-Hfur(min)), 4.40 (1 H, d, J 4.8, 6-Hfur(min)), 4.38 (1 H, m, 4-Hpyr), 4.31-4.24 (2 Hpyr, 2 Hfur(maj) and 2 Hfur(min), m, 3 x OCH2), 4.20 (1 H, t, J 4.8, 5-Hfur(min)), 4.13-4.04 (1 Hfur(maj) and 1 Hpyr, m, 5-Hfur(maj) and 6-
H\textsubscript{pyr}), 4.25-3.75 (3 H\textsubscript{pyr}, 3 H\textsubscript{fur(maj)} and 3 H\textsubscript{fur(min)}, br. s, 9 × OH), 3.66-3.11 (4 H\textsubscript{pyr}, 4 H\textsubscript{fur(maj)} and 4 H\textsubscript{fur(min)}, m, 6 × NCH\textsubscript{2}H\textsubscript{2}), 2.72 (1 H, dd, \textsuperscript{2}J 13.7 and \textsuperscript{J} 6.8, 3-H\textsubscript{A fur(min)}, 2.56 (1 H, dd, \textsuperscript{2}J 13.5 and \textsuperscript{J} 7.3, 3-H\textsubscript{A fur(maj)}, 2.45 (1 H, dd, \textsuperscript{2}J 13.5 and \textsuperscript{J} 7.3, 3-H\textsubscript{B fur(maj)}, 2.28 (1 H, dd, \textsuperscript{2}J 10.7 and \textsuperscript{J} 3.2, 3-H\textsubscript{A pyr}), 2.23 (1 H, dd, \textsuperscript{2}J 13.7 and \textsuperscript{J} 4.3, 3-H\textsubscript{B fur(min)}, 2.21 (1 H, dd, \textsuperscript{2}J 10.7 and \textsuperscript{J} 7.3, 3-H\textsubscript{B pyr}), 1.64-1.56 (4 H\textsubscript{pyr}, 4 H\textsubscript{fur(maj)} and 4 H\textsubscript{fur(min)}, m, 6 × NCH\textsubscript{2}CH\textsubscript{2}); \textsuperscript{13}C (75 MHz, CDCl\textsubscript{3}) 171.7 (7-Cfur(min)), 171.3 (7-Cfur(maj)), 170.9 (1-Cfur(maj)), 170.1 (1-Cfur(min)), 169.5 (1-Cpyr), 168.7 (7-Cpyr), 102.7 (2-Cfur(maj)), 102.2 (2-Cfur(min)), 96.2 (2-Cpyr), 88.3 (5-Cfur(min)), 88.2 (5-Cfur(min)), 72.4 (4-Cfur(min)), 71.0 (4-Cfur(maj)), 69.5 (6-Cfur(maj)), 69.0 (6-Cfur(min)), 68.5 (4-Cpyr), 68.2 (6-Cpyr), 67.1 (5-Cpyr), 63.4 (OEt), 63.0 (OEt), 62.6 (OEt), 49.7 (NPr\textsubscript{2}), 49.5 (NPr\textsubscript{2}), 49.4 (NPr\textsubscript{2}), 48.4 (NPr\textsubscript{2}), 48.2 (NPr\textsubscript{2}), 48.1 (NPr\textsubscript{2}), 43.9 (3-Cfur(maj)), 43.2 (3-Cfur(min)), 35.9 (3-Cpyr), 22.5 (NPr\textsubscript{2}), 22.5 (NPr\textsubscript{2}), 22.3 (NPr\textsubscript{2}), 21.0 (NPr\textsubscript{2}), 20.9 (NPr\textsubscript{2}), 14.6 (OEt), 14.5 (OEt), 14.4 (OEt), 11.8 (NPr\textsubscript{2}), 11.8 (NPr\textsubscript{2}), 11.6 (NPr\textsubscript{2}), 11.5 (NPr\textsubscript{2}) and 11.5 (NPr\textsubscript{2}); m/z (ES) 356 (18, MNa\textsuperscript{+}) and 334 (100, MH\textsuperscript{+}). (Found: MNa\textsuperscript{+}, 356.1693. C\textsubscript{15}H\textsubscript{27}NO\textsubscript{7} requires MNa, 356.1685).

Analysis by 500 MHz \textsuperscript{1}H NMR revealed a 41 : 39 : 20 mixture of two furanose and one pyranose forms.

(4R, 5R, 6R)-6-Dipropylcarbamoyl-2-oxo-4,5,6-trihydroxy-hexanoic acid ammonium salt 42

Barium hydroxide monohydrate (88 mg, 0.46 mmol) in water (21 mL) was added slowly to a solution of the ester 41 (309 mg, 0.93 mmol) in methanol (4.3 mL) and the mixture stirred at room temperature for 16 h. The mixture was evaporated under reduced pressure, the residue dissolved in water (15 mL) and ammonium sulfate (61 mg, 0.46 mmol) added. The mixture was stirred for 2 h at room temperature, the precipitate removed by filtration through a 4 µm filter and the filtrate evaporated under reduced pressure to give the ammonium salt 42 (289 mg, 97%) as a pale yellow foam, \textit{Rf} 0.58 (5 : 2 : 2 EtOAc–AcOH–H\textsubscript{2}O); \textit{[\alpha]}\textsc{D}\textsubscript{20} \textsuperscript{20} 31.0 (c. 1.11 in H\textsubscript{2}O); \textit{v}_{\text{max}}/\text{cm}^{-1} (solid) 3600–2500 (br.) and 1618; \textit{\delta}_{\text{H}} (500 MHz, D\textsubscript{2}O) 4.70 (1 H, d, J 9.9, 6-H\textsubscript{pyr}), 4.38 (1 H, d, J 5.6, 6-H\textsubscript{fur(maj)}), 4.31 (1 H, d, J 6.8, 6-H\textsubscript{fur(min)}), 4.33-4.25 (1 H fur(maj)) and
1 Hfur(min), m, 4-Hfur(maj) and 4-Hfur(min)), 3.99-3.94 (1 Hfur(maj) and 1 Hpyr, m, 5-Hfur(maj) and 4-Hpyr), 3.84 (1 H, dd, J = 6.8 and 3.9, 5-Hfur(min)), 3.64 (1 H, dd, J = 9.9 and 3.2, 5-Hpyr), 3.33-2.79 (4 Hpyr, 4 Hfur(maj) and 4 Hfur(min), m, 6 × NC₂H₂), 2.31 (1 H, dd, 2J = 14.1 and 2J = 7.3, 3-HA fur(maj)), 2.11 (1 H, dd, 2J = 14.1 and 2J = 6.8, 3-HA fur(min)), 2.03 (1 H, dd, 2J = 14.1 and 2J = 5.6, 3-HB fur(min)), 1.88 (1 H, dd, 2J = 15.0 and 2J = 3.4, 3-HB pyr), 1.77 (1 H, dd, 2J = 14.1 and 2J = 2.6, 3-HA pyr), 1.68 (1 H, dd, 2J = 15.0 and 2J = 3.4, 3-HB pyr), 1.56-1.19 (4 Hpyr, 4 Hfur(maj) and 4 Hfur(min), m, 6 × NCH₂CH₂C₂H₃) and 0.66-0.53 (6 Hpyr, 6 Hfur(maj) and 6 Hfur(min), m, 6 × NCH₂CH₂CH₂CH₃); δC (75 MHz, D₂O) 176.9 (1-Cfur(min)), 176.4 (1-Cfur(maj)), 176.4 (1-Cpyr), 171.9 (7-Cfur(min)), 171.4 (7-Cfur(maj)), 171.3 (7-Cpyr), 104.7 (2-Cfur(maj)), 104.3 (2-Cfur(min)), 96.7 (2-Cpyr), 87.3 (5-Cfur(maj)), 87.0 (5-Cfur(min)), 72.2 (4-Cfur(min)), 71.7 (4-Cfur(maj)), 68.7 (5-Cpyr), 68.6 (6-Cfur(min)), 68.4 (6-Cfur(maj)), 67.6 (4-Cpyr), 65.8 (6-Cpyr), 50.5 (Pr), 49.8 (Pr), 49.7 (Pr), 49.3 (Pr), 48.6 (Pr), 48.4 (Pr), 44.7 (3-Cfur(maj)), 43.7 (3-Cfur(min)), 37.1 (3-Cpyr), 22.4 (Pr), 22.4 (Pr), 22.0 (Pr), 20.6 (Pr), 20.5 (Pr), 20.5 (Pr), 10.9 (Pr), 10.9 (Pr), 10.9 (Pr), 10.8 (Pr), 10.6 (Pr) and 10.6 (Pr); m/z (ES) 306 (100%, [M−NH₃]H⁺). (Found: [M−NH₃]Na⁺, 328.1372). C₁₃H₂₃NO₇·NH₃ requires [M−NH₃]Na⁺, 328.1372).

Analysis by 500 MHz ¹H NMR revealed a 38 : 33 : 29 mixture of two furanose and one pyranose forms.

(4R, 5R, 6R)-6-Dipropylcarbamoyl-2-oxo-4,5,6-trihydroxy-hexanoic acid 43

Ion-exchange chromatography (Dowex 1X8–100, formate form, gradient elution: 0 → 1.0 M formic acid) of the ammonium salt 42 (100 mg, 0.31 mmol) gave the acid 43 (68 mg, 72%; 97 : 3, 4R : 4S) as a colourless foam, Rf 0.58 (5 : 2 : 2 EtOAc–AcOH–H₂O); [α]₂₀°D −35.4 (c. 1.30 in H₂O); νmax/cm⁻¹ (solid) 3392 (br.), 2967, 2877, 1736 and 1621; δ (500 MHz, D₂O) 4.95 (1 H, d, J = 9.8, 6-Hpyr(maj)), 4.93 (1 H, d, J = 9.0, 6-Hpyr(min)), 4.57 (1 H, ddd, J = 6.4, 5.8 and 3.9, 4-Hfur(min)), 4.54 (1 H, d, J = 6.8, 6-Hfur(min)), 4.52 (1 H, app. dt, J = 7.0 and 2.6, 4-Hfur(maj)), 4.46 (1 H, d, J = 7.3, 6-Hfur(maj)), 4.25 (1 H, dd, J = 7.3 and 2.6, 5-Hfur(maj)), 4.20 (1 H, q, J = 3.4, 4-Hpyr(maj)), 4.16 (1 H, ddd, J = 5.1, 3.0 and 2.6, 4-Hpyr(min)), 4.10 (1 H, dd, J = 6.8 and 3.9, 5-Hfur(min)), 3.93 (1 H, dd, J = 9.0 and 3.0, 5-Hpyr(min)), 3.86 (1 H, dd, J = 9.8 and 3.4, 5-Hpyr(maj)), 3.60-3.05 (4 Hfur(maj), 4 Hpyr(maj) and 4 Hpyr(min), m, 2 × NC₂H₂ fur(maj), 2 × NC₂H₂ fur(min), 2 × NC₂H₂ pyr(maj) and
2 × NCH₂pyr(min)), 2.64 (1 H, dd, 2J 14.5 and J 6.8, 3-Hₐ fur(maj)), 2.54 (1 H, dd, 2J 14.1 and J 5.1, 3-Hₐ pyr(min)), 2.42 (1 H, dd, 2J 15.0 and J 5.8, 3-Hₐ fur(min)), 2.39 (1 H, dd, 2J 15.0 and J 6.4, 3-Hₐ fur(min)), 2.15 (1 H, dd, 2J 15.0 and J 3.4, 3-Hₐ pyr(maj)), 2.11 (1 H, dd, 2J 15.0 and J 3.4, 3-Hₐ pyr(maj)), 2.09 (1 H, dd, 2J 14.5 and J 2.6, 3-Hₐ fur(maj)), 1.90 (1 H, dd, 2J 14.1 and J 2.6, 3-Hₐ pyr(maj)), 1.67-1.35 (4 H furyl(maj), 4 H furyl(min), 4 H pyr(maj) and 4 H pyr(min), m, 2 × NCH₂CH₂ fur(maj), 2 × NCH₂CH₂ pyr(maj) and 2 × NCH₂CH₂ pyr(min)) and 0.87-0.35 (6 H furyl(maj), 6 H furyl(min), 6 H pyr(maj) and 6 H pyr(min), m, 2 × NCH₂CH₂CH₃ fur(maj), 2 × NCH₂CH₂CH₃ furyl(min), 2 × NCH₂CH₂CH₃ pyr(maj) and 2 × NCH₂CH₂CH₃ pyr(min)); δC (75 MHz, D₂O) 173.5 (1-C fur(min)), 173.2 (1-C pyr(min)), 172.9 (1-C fur(maj)), 172.9 (1-C pyr(maj)), 172.2 (7-C fur(min)), 172.1 (7-C fur(maj)), 170.5 (7-C pyr(min)), 170.2 (7-C pyr(maj)), 103.2 (2-C fur(maj)), 102.9 (2-C fur(min)), 95.5 (2-C pyr(maj)), 88.1 (5-C fur(min)), 87.3 (5-C fur(maj)), 72.1 (4-C fur(min)), 72.1 (4-C fur(maj)), 71.5 (4-C fur(min)), 71.7 (5-C pyr(min)), 70.3 (5-H pyr(maj)), 68.2 (6-C fur(min)), 67.7 (6-C fur(maj)), 67.0 (4-H pyr(maj)), 66.6 (4-C pyr(min)), 65.7 (6-C pyr(maj)), 65.6 (6-C pyr(min)), 50.3 (Pr), 50.0 (Pr), 49.8 (Pr), 49.8 (Pr), 49.2 (Pr), 48.9 (Pr), 48.6 (Pr), 48.4 (Pr), 44.2 (3-C fur(min)), 43.7 (3-C fur(maj)), 38.8 (3-C pyr(min)), 36.7 (3-C pyr(maj)), 22.4 (Pr), 22.3 (Pr), 22.1 (Pr), 22.1 (Pr), 20.6 (Pr), 20.5 (Pr), 20.5 (Pr), 20.5 (Pr), 10.9 (Pr), 10.9 (Pr), 10.8 (Pr), 10.7 (Pr), 10.7 (Pr), 10.6 (Pr), 10.6 (Pr) and 10.6 (Pr), (1 peak missing); m/z (ES) 328 (70%, MNa⁺), 306 (45, MH⁺). (Found: MNa⁺, 328.1382. C₁₃H₂₃NO₇ requires MNa, 328.1372).

Analysis by 500 MHz ¹H NMR revealed that the R-isomer existed as a 44 : 32 : 16 : 8 mixture of two furanose and two pyranose forms.

(4S, 5R, 6R)-6-Dipropylcarbamoyl-2-oxo-4-hydroxy-5,6-O-isopropylidene-hexanoic acid ethyl ester 44

A solution of the amide 26 (48 mg, 0.13 mmol) in methanol (4 mL) at −78 °C was subjected to ozonolysis, following addition of dimethylsulfide (0.8 mL), the mixture was warmed to room temperature, stirred for 2.5 h and evaporated under reduced pressure. Purification by flash chromatography, eluting with 70 : 30 petrol–ethyl acetate gave the ketone 44(21 mg, 42%) as a pale yellow oil, Rₜ 0.36 (50% EtOAc in petrol); [α]D²⁰ +23.0 (c, 2.1 in CDCl₃); νmax/cm⁻¹ (film) 3369, 2966, 1783, 1729 and 1639; δH (500 MHz, CDCl₃) 4.96 (1 H, d, J 6.6,
6-H), 4.31 (2 H, q, \( J = 7.2 \), OCH\(_2\)), 4.26 (2 H, m, 5-H and OH), 4.02 (1 H, m, 4-H), 3.52-3.20 (4 H, m, 2 × NC\( \text{H}_2 \)), 3.21 (1 H, dd, \( J = 18.1 \) and \( J = 5.9 \), 3-H\( \text{A} \)), 3.07 (1 H, dd, \( J = 18.1 \) and \( J = 7.0 \), 3-HB), 1.74-1.55 (4 H, m, 2 × NCH\( \text{H}_2 \)), 1.65 (3 H, s, C\( \text{Me} \)), 1.39 (3 H, s, C\( \text{Me} \)), 1.36 (3 H, t, \( J = 7.2 \), OCH\(_2\)C\( \text{H}_3 \)), 0.97 (3 H, t, \( J = 7.3 \), NCH\(_2\)CH\(_2\)C\( \text{H}_3 \)) and 0.92 (3 H, t, \( J = 7.4 \), NCH\(_2\)CH\(_2\)C\( \text{H}_3 \)); \( \delta \)C (75 MHz, CDCl\(_3\)) 193.6, 168.7, 161.1, 111.2, 79.0, 74.7, 67.5, 63.1, 50.2, 49.4, 43.2, 26.5, 26.4, 23.2, 21.2, 14.5, 11.9 and 11.8; m/z (ES) 406 (30, M+MeOH\(_2^+\)) and 374 (100, MH\(^+\)).

(Found: MH\(^+\), 374.2174. C\(_{18}\)H\(_{31}\)NO\(_7\) requires MH\(^+\), 374.2179).

\((4S, 5R, 6R)-6\)-Dipropylcarbamoyl-2-oxo-4,5,6-trihydroxy-hexanoic acid ethyl ester 45

The amide 44 (20 mg, 0.054 mmol) was treated with trifluoroacetic acid–water (1:1, 2 mL), the mixture swirled for 2 min and evaporated under reduced pressure. The process was repeated, purification by flash chromatography, eluting with ethyl acetate, gave the amide 45 (9.2 mg, 51%) as a colourless oil, \( R_f = 0.40 \) (EtOAc); \( [\alpha]_D^{20} = -43.3 \) (c. 4.43 in CHCl\(_3\)); \( \nu_{\text{max}}/\text{cm}^{-1} \) (film) 3368, 2967, 1742 and 1636; \( \delta_H \) (500 MHz, CDCl\(_3\)) 4.81 (1 H, d, \( J = 8.5 \), 6-Hfur(maj)), 4.74 (1 H, d, \( J = 8.4 \), 6-Hfur(min)), 4.67 (1 H, ddd, \( J = 5.8 \) and 1.9, 4-Hfur(min)), 4.64 (1 H, m, 4-Hfur(maj)), 4.41 (1 H, d, \( J = 9.3 \), 6-Hpyr), 4.32-4.23 (2 Hpyr, 2 Hfur(maj) and 2 Hfur(min), m, 3 × OCH\(_2\)H), 4.12-4.07 (1 H, m, 5-Hfur(min)), 4.10 (1 H, ddd, \( J = 16.7 \), 9.3 and 6.5, 4-Hpyr), 3.94 (1 H, m, 4-Hfur(maj)), 3.91 (1 H, t, \( J = 9.3 \), 5-Hpyr), 3.32-3.00 (4 Hpyr, 4 Hfur(maj) and 4 Hfur(min), m, 6 × NC\( \text{H}_2 \)), 2.64 (1 H, dd, \( J = 14.0 \) and 5.1, 3-HA fur(maj)), 2.60 (1 H, dd, \( J = 14.7 \) and 1.9, 3-HA fur(min)), 2.41 (1 H, dd, \( J = 14.7 \) and 5.8, 3-HB fur(min)), 2.27 (1 H, d, \( J = 14.0 \), 3-HB fur(maj)), 2.16 (1 H, dd \( J = 16.7 \) and \( J = 12.8 \), 3-HA pyr), 2.12 (1 H, dd, \( J = 12.8 \) and \( J = 6.5 \), 3-HB pyr), 1.60-1.54 (4 Hpyr, 4 Hfur(maj) and 4 Hfur(min), m, 6 × NCH\(_2\)CH\(_2\)H), 1.35-1.28 (3 Hpyr, 3 Hfur(maj) and 3 Hfur(min), m, 3 × OCH\(_2\)CH\(_3\)) and 0.93-0.85 (6 Hpyr, 6 Hfur(maj) and 6 Hfur(min), m, 6 × NCH\(_2\)CH\(_2\)CH\(_3\)); \( \delta_C \) (75 MHz, CDCl\(_3\)) 172.8 (7-Cfur(maj)), 172.8 (7-Cfur(min)), 170.9 (1-Cfur(min)), 170.2 (1-Cpyr), 170.1 (1-Cfur(maj)), 168.7 (7-Cpyr), 103.3 (2-Cfur(maj)), 102.8 (2-Cfur(min)), 95.8 (2-Cpyr), 86.8 (5-Cfur(maj)), 85.4 (5-Cfur(min)), 73.4 (4-Cpyr), 73.1 (4-Cfur(min)), 72.4 (4-Cfur(maj)), 70.9 (6-Cpyr), 68.2 (5-Cpyr), 66.8 (6-Cfur(maj)), 66.0 (6-Cfur(min)), 63.6 (Et), 63.2 (Et), 62.8 (Et), 49.6 (Pr), 49.3 (Pr), 49.2 (Pr), 48.4 (Pr), 48.1 (Pr), 48.0 (Pr), 44.4 (3-Cfur(min)), 43.2 (3-Cfur(maj)), 37.7 (3-Cpyr), 22.4 (Pr), 22.4 (Pr), 22.3 (Pr), 21.0 (Pr), 20.9 (Pr), 20.9 (Pr), 14.5 (Et), 14.4 (Et), 14.3 (Et), 11.7 (Pr),
11.6 (Pr), 11.5 (Pr), 11.5 (Pr) and 11.5 (Pr); \( m/z \) (ES) 356 (48%, MNa\(^+\)) and 334 (100, MH\(^+\)). (Found: MH\(^+\), 334.1859. C\(_{15}\)H\(_{27}\)NO\(_7\) requires MH\(^+\), 334.1866).

Analysis by 500 MHz \(^1\)H NMR revealed an initial mixture of 72 : 14 : 14 one pyranose and two furanose forms, which equilibrated over 9 days in CDCl\(_3\) to a 53 : 29 : 18 mixture of one pyranose and two furanose forms forms.

(4S, 5R, 6R)-6-Dipropylcarbamoyl-2-oxo-4,5,6-trihydroxy-hexanoic acid ammonium salt 46

Barium hydroxide monohydrate (140 mg, 0.74 mmol) in water (34 mL) was added slowly to a solution of the ester 45 (493 mg, 1.48 mmol) in methanol (7 mL) and the mixture stirred at room temperature for 23 h and evaporated under reduced pressure. The residue was dissolved in water (23 mL), ammonium sulphate (98 mg, 0.74 mmol) added, the mixture stirred for 2 h at room temperature, the precipitate removed by filtration through Celite and the filtrate evaporated under reduced pressure to give the ammonium salt 46 (474 mg, quantitative) as a colourless foam, \( R_f \) 0.58 (5 : 2 : 2 EtOAc–AcOH–H\(_2\)O); \([\alpha]_D^{20} -20.2 \) (c. 1.04 in H\(_2\)O); \( \nu_{max}/cm^{-1} \) (solid) 3310 (br.), 2968, 2877 and 1621; \( \delta_H \) (500 MHz, D\(_2\)O) 4.78 (1 H, d, \( J \) 9.0, 6-H\(_{fur}\)), 4.56 (1 H, d, \( J \) 9.4, 6-H\(_{pyr(maj)}\)), 4.45 (1 H, d, \( J \) 9.4, 6-H\(_{pyr(min)}\)), 4.40 (1 H, dd, \( J \) 4.7 and 2.8, 4-H\(_{fur}\)), 4.12 (1 H, dd, \( J \) 9.0 and 2.8, 5-H\(_{fur}\)), 3.92 (1 H, ddd, \( J \) 11.7, 9.4 and 5.1, 4-H\(_{pyr(maj)}\)), 3.84 (1 H, ddd, \( J \) 12.0, 9.4 and 5.1, 4-H\(_{pyr(min)}\)), 3.62 (1 H, ddd, \( J \) 9.4, 5-H\(_{pyr(maj)}\)), 3.60 (1 H, dt, \( J \) 15.0 and 7.5, NCH\(_A\)\(_{pyr(maj)}\)), 3.37 (1 H, ddd, \( J \) 15.0, J 8.6 and 6.4, NCH\(_A\)\(_{pyr(min)}\)), 3.25 (1 H, dt, \( J \) 15.0 and J 7.7, NCH\(_B\)\(_{pyr(maj)}\)), 3.18 (1 H, ddd, \( J \) 15.0, J 8.6 and 6.4, NCH\(_B\)\(_{pyr(min)}\)), 3.51-3.05 (4 Hpyr(min) and 4 H\(_{fur}\)), 2.50 (1 H, dd, \( J \) 12.8 and J 5.1, 3-H\(_A\)\(_{pyr(min)}\)), 2.37 (1 H, d, \( J \) 14.5, 3-H\(_A\)\(_{fur}\)), 2.27 (1 H, dd, \( J \) 14.5 and J 4.7, 3-H\(_B\)\(_{fur}\)), 2.11 (1 H, dd \( J \) 13.1 and J 5.1, 3-H\(_A\)\(_{pyr(min)}\)), 2.11 (1 H, m, 3-H\(_B\)\(_{pyr(min)}\)), 1.84 (1 H, app. t, \( J \) 12.4, 3-H\(_B\)\(_{pyr(maj)}\)), 1.64-1.44 (4 Hpyr(min)), 4 Hpyr(min) and 4 H\(_{fur}\), m, 2 × NCH\(_2\)CH\(_2\)\(_{pyr(maj)}\)), 2 × NCH\(_2\)CH\(_2\)\(_{pyr(min)}\) and 2 × NCH\(_2\)CH\(_2\)\(_{fur}\) (H\(_{pyr(min)}\)) and \( \delta_C \) (75 MHz, D\(_2\)O, major pyranose anomer only) 175.9, 170.6, 97.6, 73.1, 69.9, 68.9, 50.4, 49.3, 39.5, 22.4, 20.6, 10.9
and 10.7; \( m/z \) (ES) 306 (100, \([M-\text{NH}_3]^+\)). (Found: \([M-\text{NH}_3]^+\), 306.1542. \(\text{C}_{13}\text{H}_{23}\text{NO}_7\text{NH}_3 \) requires \([M-\text{NH}_3]^+\), 306.1553).

Analysis by 500 MHz \(^1\text{H} \) NMR revealed a 84 : 7 : 9 mixture of two pyranose and one furanose forms.

\((4S, 5R, 6R)-6\text{-Dipropylcarbamoyl-2-oxo-4,5,6-tri hydroxy-hexanoic acid 47}\)

Ion-exchange chromatography (Dowex 1X8–100, formate form, gradient elution: 0 → 1.0 M formic acid) of the ammonium salt \( 46 \) (100 mg, 0.31 mmol) gave the acid \( 47 \) (74 mg, 79%) as a colourless foam, \( R_f \) 0.58 (5 : 2 : 2 EtOAc–AcOH–H\(_2\)O); \([\alpha]_D^{20} -30.6 \) (c. 1.24 in H\(_2\)O);

\(\nu_{\text{max}}/\text{cm}^{-1} \) (solid) 3392 (br) 2968, 2878, 1737 and 1621; \(\delta_H \) (500 MHz, D\(_2\)O) 3.87 (1 H, d, \(J\) 9.0, 6-H\(_{\text{fur(min)}}\)), 4.80 (1 H, d, J 9.0, 6-H\(_{\text{fur(maj)}}\)), 4.61 (1 H, d, J 9.4, 6-H\(_{\text{pyr(maj)}}\)), 4.58-4.53 (1 H\(_{\text{fur(maj)}}\) and 1 H\(_{\text{fur(min)}}\), m, 4-H\(_{\text{fur(min)}}\) and 4-H\(_{\text{fur(maj)}}\)), 4.33 (1 H, d, J 9.4, 6-H\(_{\text{pyr(min)}}\)), 4.16 (1 H, dd, J 9.0 and 3.4, 5-H\(_{\text{fur(maj)}}\)), 4.10 (1 H, dd, J 9.0 and 3.4, 5-H\(_{\text{fur(min)}}\)), 3.95 (1 H, ddd, J 11.5, 9.4 and 5.1, 4-H\(_{\text{pyr(maj)}}\)), 3.79 (1 H, ddd, J 12.0, 9.4 and 5.1, 4-H\(_{\text{pyr(min)}}\)), 3.64 (1 H, t, J 9.4, 5-H\(_{\text{pyr(maj)}}\)), 3.6-3.62 (1 H, m, 5-H\(_{\text{pyr(min)}}\)), 3.44 (1 H, dt, \(^2J\) 15.0 and J 7.7, NCH\(_{A \text{pyr(maj)}}\)), 3.35 (1 H, ddd, \(^2J\) 13.7, J 8.6 and 6.4, NCH\(_{A \text{pyr(maj)}}\)), 3.25 (1 H, dt, \(^2J\) 15.0 and J 7.7, NCH\(_{B \text{pyr(maj)}}\)), 3.19 (1 H, ddd, \(^2J\) 13.7, J 8.6 and 6.4, NCH\(_{B \text{pyr(maj)}}\)), 3.60-3.00 (4 H\(_{\text{fur(maj)}}\), 4 H\(_{\text{fur(min)}}\) and 4 H\(_{\text{pyr(min)}}\), m, 2 × NCH\(_2\)H\(_2\)f(maj), 2 × NCH\(_2\)H\(_2\)f(maj), and 2 × NCH\(_2\)H\(_2\)pyr(min)), 2.61-2.55 (1 H\(_{\text{fur(maj)}}\), 1 H\(_{\text{fur(min)}}\) and 1 H\(_{\text{pyr(min)}}\), m, , 3-H\(_A\)H\(_{\text{fur(min)}}\), 3-H\(_A\)H\(_{\text{fur(min)}}\) and 3-H\(_A\)H\(_{\text{pyr(min)}}\)), 2.34 (1 H, dd, \(^2J\) 15.0 and J 5.6, 3-H\(_B\)H\(_{\text{fur(maj)}}\)), 2.23 (1 H, dd \(^2J\) 13.3 and J 5.1, 3-H\(_A\)H\(_{\text{pyr(min)}}\)), 2.17 (1 H, d, \(^2J\) 14.5, 3-H\(_B\)H\(_{\text{fur(min)}}\)), 1.84 (1 H, dd, \(^2J\) 13.3 and J 11.5, 3-H\(_B\)H\(_{\text{pyr(maj)}}\)), 1.68 (1 H, dd, \(^2J\) 12.8 and J 12.0, 3-H\(_B\)H\(_{\text{pyr(min)}}\)), 1.60-1.40 (4 H\(_{\text{pyr(maj)}}\), 4 H\(_{\text{pyr(min)}}\), 4 H\(_{\text{fur(maj)}}\) and 4 H\(_{\text{fur(min)}}\), m, 2 × NCH\(_2\)CH\(_2\)H\(_2\)pyr(maj), 2 × NCH\(_2\)CH\(_2\)pyr(maj), 2 × NCH\(_2\)CH\(_2\)H\(_2\)fur(maj) and 2 × NCH\(_2\)CH\(_2\)H\(_2\)fur(maj)), 0.82 (3 H, t, J 7.3, NCH\(_2\)CH\(_2\)CH\(_3\)pyr(maj)), 0.80 (3 H, t, J 7.3, NCH\(_2\)CH\(_2\)CH\(_3\)pyr(maj)) and 0.85-0.76 (6 H\(_{\text{pyr(min)}}\), 6 H\(_{\text{fur(maj)}}\) and 6 H\(_{\text{fur(min)}}\), m, 2 × NCH\(_2\)CH\(_2\)CH\(_3\)pyr(min), 2 × NCH\(_2\)CH\(_2\)CH\(_3\)fur(maj) and 2 × NCH\(_2\)CH\(_2\)CH\(_3\)fur(min)); \(\delta_C \) (75 MHz, D\(_2\)O, major pyranose anomer only) 172.6, 169.9, 96.4, 72.7, 69.7, 68.3, 50.3, 49.2, 39.0, 22.4, 20.5, 10.9 and 10.7; \( m/z \) (ES) 328 (100%, M\(_{\text{Na}^+}\)), 306 (85, M\(^+\)–OH). (Found: M\(_{\text{Na}^+}\), 328.1377. \(\text{C}_{13}\text{H}_{23}\text{NO}_7\) requires M\(_{\text{Na}^+}\), 328.1372).
Analysis by 500 MHz $^1$H NMR revealed a 79 : 8 : 7 : 6 mixture of two pyranose and two furanose forms.

(2R, 3R)-2,3-O-Isopropylidene-pent-4-enoic acid dipropylamide 35
Dipropylamine (103 µl, 0.75 mmol), 1-hydroxybenzotriazole (101 mg, 0.75 mmol), and 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide hydrochloride (144 mg, 0.75 mmol) were added to a solution of the acid $^6$ 34 (86 mg, 0.50 mmol) in ethyl acetate (8 mL). The solution was stirred under N$_2$ for 18 h, water (10 mL) and ethyl acetate (10 mL) added, the aqueous layer extracted with ethyl acetate (3 × 10 mL), dried (MgSO$_4$) and evaporated under reduced pressure. Purification by flash chromatography, eluting with 80 : 20 petrol–ethyl acetate, gave the dipropylamide 35 (99 mg, 77%) as a colourless oil, $R_f$ 0.42 (40% EtOAc in petrol); $[\alpha]_D^{20}$ $-28.6$ (c. 0.91 in CHCl$_3$); $\nu_{\text{max}}$/cm$^{-1}$ (film) 2965, 2875, 1660 and 1455; $\delta_H$ (500 MHz, CDCl$_3$) 5.80 (1 H, ddd, $J_{17.1}$, 10.3 and 7.7, 4-H), 5.40 (1 H, d, $J_{17.1}$, 5-H$_{\text{trans}}$), 5.24 (1 H, d, $J_{10.3}$, 5-H$_{\text{cis}}$), 4.94 (1 H, d, $J_{7.7}$, 2-H), 4.78 (1 H, t, $J_{7.7}$, 3-H), 3.49 (1 H, dt, $J_{13.3}$ and $J_{7.7}$, NC$_2$H$_A$), 3.15-3.00 (3 H, m, 3 × NC$_2$H), 1.66 (3 H, s, CMe), 1.65-1.47 (4 H, m, 2 × NCH$_2$C$_2$H$_2$), 1.41 (3 H, s, CMe), 0.91 (3 H, t, $J_{7.3}$, CH$_2$CH$_3$) and 0.88 (3 H, t, $J_{7.3}$, CH$_2$CH$_3$); $\delta_C$ (75 MHz, CDCl$_3$) 167.9, 134.2, 120.2, 111.1, 79.8, 76.1, 49.4, 48.6, 27.3, 25.9, 22.6, 21.1, 11.9 and 11.6; $m/z$ (ES) 256 (100%, MH$^+$). (Found: MH$^+$, 256.1903. C$_{14}$H$_{25}$NO$_3$ requires MH$^+$, 256.1913).

(2R, 3R)-2,3-Dihydroxy-pent-4-enoic acid dipropylamide 36
Trifluoroacetic acid–water (9 : 1, 2 mL) was added to the amide 35 (26 mg, 0.10 mmol), the mixture swirled for 2 min and evaporated under reduced pressure. Purification by flash chromatography, eluting with 60 : 40 petrol–ethyl acetate gave the dipropylamide 36 (16 mg, 74%) as colourless needles; m.p. 77.4-79.1 °C (from CH$_2$Cl$_2$); $R_f$ 0.27 (50% EtOAc in petrol); $[\alpha]_D^{20}$ $+17.1$ (c. 0.84 in CHCl$_3$); (Found: C, 61.4; H, 9.80; N, 6.5; C$_{11}$H$_{21}$NO$_3$ requires: C, 61.5; H, 9.75; N, 6.5); $\nu_{\text{max}}$/cm$^{-1}$ (film) 3324, 2967, 2875, 1620 and 1475; $\delta_H$ (500 MHz, CDCl$_3$) 5.81 (1 H, ddd, $J_{16.9}$, 10.5 and 6.0, 4-H), 5.34 (1 H, d, $J_{16.9}$, 5-H$_{\text{trans}}$), 5.25 (1 H, d, $J_{10.5}$, 5-H$_{\text{cis}}$), 4.44 (1 H, dd, $J_{8.6}$ and 4.3, 2-H), 4.23 (1 H, ddd, $J_{9.4}$, 6.0 and 4.3, 3-H), 3.66
(1 H, d, J 8.6, 2-OH), 3.58 (1 H, ddd, J 8.6 and 6.8, NC\textsubscript{A}H\textsubscript{A}), 3.36 (1 H, ddd, J 15.4, J 9.0 and 7.3, NC\textsubscript{B}H\textsubscript{A}), 3.16 (1 H, ddd, J 15.4, J 8.6 and 6.8, NC\textsubscript{A}H\textsubscript{B}), 3.05 (1 H, ddd, J 15.0, J 8.5 and 6.8, NC\textsubscript{B}H\textsubscript{B}) 2.98 (1 H, d, J 9.4, 3-OH), 1.68-1.50 (4 H, m, 2 × NCH\textsubscript{2}C\textsubscript{H}\textsubscript{2}), 0.93 (3 H, t, J 7.5, CH\textsubscript{2}C\textsubscript{H}\textsubscript{3}) and 0.90 (3 H, t, J 7.5, CH\textsubscript{2}C\textsubscript{H}\textsubscript{3}); δ\textsubscript{C} (75 MHz, CDCl\textsubscript{3}) 171.5, 135.6, 118.1, 74.3, 70.9, 49.2, 48.0, 22.6, 21.1, 11.8 and 11.5; m/z (ES) 238 (30%, MNa\textsuperscript{+}), 216 (100, MH\textsuperscript{+}). (Found: MH\textsuperscript{+} 216.1609, C\textsubscript{11}H\textsubscript{21}NO\textsubscript{3} requires MH\textsuperscript{+}, 216.1600).

(6\textit{R}, 5\textit{R}, 4\textit{S})-6-Dipropylcarbamoyl-2-methylidene-4,5,6-trihydroxy-hexanoic acid ethyl ester 37

A solution of the amide 36 (1.50 g, 6.98 mmol) in methanol (70 mL) at −78 °C was subjected to ozonolysis, following addition of dimethylsulfide (7 mL), the mixture was warmed to room temperature, stirred for 3 h and evaporated under reduced pressure. The residue was redissolved in tetrahydrofuran–water (1 : 1, 100 mL), ethyl α-bromomethyl acrylate\textsuperscript{5} (1.2 mL, 8.4 mmol), and indium (882 mg, 7.68 mmol) were added and the mixture stirred for 15 h. After filtration through Celite, ethyl acetate (75 mL) was added, the organic layer separated and the aqueous layer extracted with ethyl acetate (2 × 50 mL). The combined organic extracts were washed with brine (100 mL), dried (MgSO\textsubscript{4}) and evaporated under reduced pressure. Purification by flash chromatography, eluting with 60 : 40 petrol–ethyl acetate gave the amide (0.99 g, 43%; 86 : 14 \textit{syn}–\textit{anti}). Recrystallisation from diethyl ether gave the diastereomically pure \textit{syn} amide 37 (0.56 g, 24%) as colourless needles, m.p. 96.9-97.5 (from Et\textsubscript{2}O); R\textsubscript{f} 0.23 (70% EtOAc in petrol); [\textalpha]\textsubscript{D}\textsuperscript{10} +16.0 (c. 0.60 in CDCl\textsubscript{3}); (Found: C, 58.0; H, 8.85; N, 4.0; C\textsubscript{16}H\textsubscript{29}NO\textsubscript{6} requires: C, 58.0; H, 8.80; N, 4.2); ν\textsubscript{max}/cm\textsuperscript{-1} (film) 3441, 3340, 2970, 1705 and 1628; δ\textsubscript{H} (300 MHz, CDCl\textsubscript{3}) 6.27 (1 H, d, J 1.3, C=CH\textsubscript{A}), 4.53 (1 H, dd, J 8.7 and 6.6, 6-H), 4.21 (2 H, q, J 7.0, OCH\textsubscript{2}), 4.00 (1 H, ddd, J 7.5, 6.1, 5.7 and 1.8, 4-H), 3.66-3.49 (2 H, m, NC\textsubscript{H}\textsubscript{2}), 3.00 (1 H, d, J 5.7, 4-OH), 2.62 (1 H, ddd, J 14.1, J 7.5 and 4\textsuperscript{J} 0.9, 3-H\textsubscript{A}), 2.57 (1 H, ddd, J 14.1, J 6.1 and 4\textsuperscript{J} 0.9, 3-H\textsubscript{B}), 1.67-1.51 (4 H, m, NCH\textsubscript{2}CH\textsubscript{2}), 0.92 (3 H, t, J 7.5, CH\textsubscript{2}CH\textsubscript{3}) and 0.91 (3 H, t, J 7.5, CH\textsubscript{2}CH\textsubscript{3}); δ\textsubscript{C} (75 MHz, CDCl\textsubscript{3}) 173.1, 168.4, 137.3, 128.8, 74.8, 70.5,
69.6, 61.6, 49.3, 48.2, 37.1, 22.4, 21.1, 14.5, 11.7 and 11.5; m/z (ES) 254 (30%, MNa+), 332 (100, MH+).

Also obtained by preparative HPLC of the supernatant was (2R, 3R, 2'S)-2,3-dihydroxy-3-(4'-methylene-5'-oxo-tetrahydro-furan-2'-yl)-N,N-dipropyl-propionamide 38 (125 mg, 7%) as colourless needles, m.p. 137.1-139.8 (from CH2Cl2); Rf 0.23 (80% EtOAc in petrol); [α]D 20 +46.4 (c. 1.12 in CDCl3); νmax/cm−1 (film) 3349, 2960, 1759 and 1619; δH (500 MHz, CDCl3) 6.21 (1 H, t, J 2.6, C=C H A), 5.64 (1 H, t, J 2.6, C=C H B), 4.89 (1 H, ddd, J 8.1, 5.6 and 2.1, 2'-H), 4.57 (1 H, d, J 7.7, 2-H), 3.64 (1 H, dd, J 7.7 and 2.1, 3-H), 3.60-3.47 (2 H, m, NCH2), 3.50-3.35 (2 H, br. s, 2- and 3-OH), 3.19-3.07 (2 H, m, NCH2), 3.04 (1 H, ddt, J 17.1, J 8.1 and J 2.6, 3'-H A), 2.97 (1 H, ddt, J 17.1, J 5.6 and J 2.6, 3'-H B), 1.71-1.48 (4 H, m, NCH2H2), 0.94 (3 H, t, J 7.7, CH2CH3) and 0.90 (3 H, t, J 7.7, CH2CH3); δC (75 MHz, CDCl3) 172.3, 170.3, 134.2, 121.9, 76.0, 75.2, 68.1, 49.1, 48.0, 29.8, 22.1, 20.7, 11.4 and 11.1; m/z (ES) 308 (55%, MNa+), 286 (100, MH+). (Found: MH+ 286.1642, C14H23NO5 requires MH+, 286.1654).

(4S, 5R, 6R)-6-Dipropylcarbamoyl-2-oxo-4,5,6-trihydroxy-hexanoic acid ethyl ester 45

A solution of the amide 37 (538 mg, 1.63 mmol) in methanol (16 mL) at −78 °C was subjected to ozonolysis, following addition of dimethylsulfide (1.6 mL), the mixture was warmed to room temperature, stirred for 2.5 h and evaporated under reduced pressure. Purification by flash chromatography, eluting with 10% ethyl acetate in petrol gave the amide 45 (545 mg, quantitative) as a colourless, spectroscopically identical to that obtained previously.

References