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Alkoxyallene-Based De Novo Synthesis of Rare Deoxy Sugars: New Routes to L-Cymarose, L-Sarmentose, L-Diginose and L-Oleandrose

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Starting from lithiated methoxyallene and lactaldehyde derivatives, the four rare 2,6-dideoxy-hexoses L-cymarose, L-sarmentose, L-diginose and L-oleandrose were synthesized in a stereodivergent fashion. Key steps towards these four target monosaccharides were the oxidative ring openings of allene-derived 2,5-dihydrofurans, diastereoselective carbonyl reductions as well as face-selective hydrogenation protocols. First glycosylation reactions employing thiophenyl glycosyl donors of L-cymarose and L-diginose were performed in high yields and with fair to excellent stereocontrol.

Introduction

Deoxy sugars, i.e. 2,6-dideoxy sugars, are essential constituents of a large number of biologically active natural glycosides.[1] Due to the very limited availability of these "rare" carbohydrates from microbial sources, new approaches for their de novo synthesis remain a topic of continuous attention.[2] We were interested in the four 2,6-dideoxy-3-*O*-methyl-L-hexoses, i.e. L-cymarose (**1**), L-sarmentose (**2**), L-diginose (**3**), and L-oleandrose (**4**) (Figure 1) because these monosaccharides occur as subunits in numerous antitumor antibiotics and yet only few synthetic routes to these carbohydrates have been reported.[3] In particular, we needed to develop a new and efficient synthesis of L-cymarose (**1**) as part of our ongoing total synthesis of the DNA-helicase inhibitor heliquinomycin[4] (**5**, Figure 2). We could earlier demonstrate the utility of lithiated alkoxyallenes as versatile C_3 building blocks in numerous applications from heterocyclic to natural product synthesis.[5] Thus, we also planned to use alkoxyallene methodology for the synthesis of carbohydrates **1**–**4** and two synthetic methods previously explored by our group emerged as key transformations for this objective (Scheme 1): (*i*) the preparation of 3-alkoxy-2,5-dihydrofurans **8** from lithiated methoxyallene **6** and aldehydes **7**[6] and (*ii*) the oxidative ring opening of these intermediates to α,β-unsaturated γ-keto aldehydes **9**.[7] For α-functionalized dihydrofuran substrates like **8**, the latter transformation resembles a parallel to the Achmatowicz reaction (the oxidation of furyl alcohols **10** to 4-enuloses **11**)[8] which is a valuable protocol for the construction of monosaccharide building blocks.[9] Subsequent elaboration of keto aldehydes **9** into sugars **1**–**4** would require installing their relative configurations at C-3 and C-4 by stereodivergent reductions of the enol ether double bond and the carbonyl group while the L-configuration at C-5 would trace back to readily available (*S*)-(–)-lactaldehydes **7**.

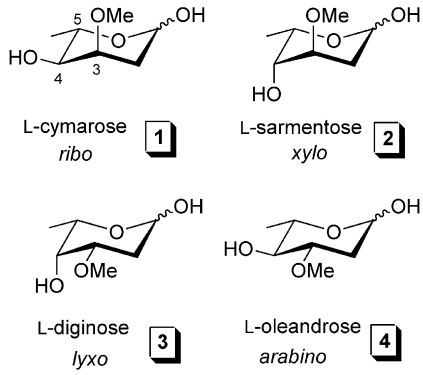

Figure 1. The four 2,6-dideoxy-3-*O*-methyl-L-hexoses.

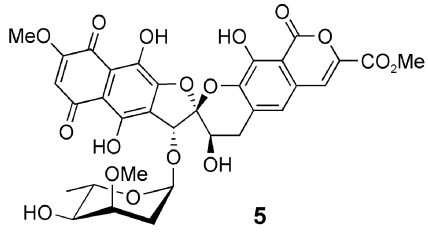

Figure 2. Structure of heliquinomycin (**5**).

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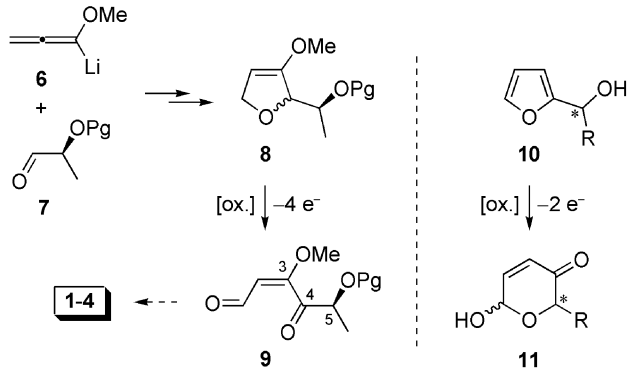
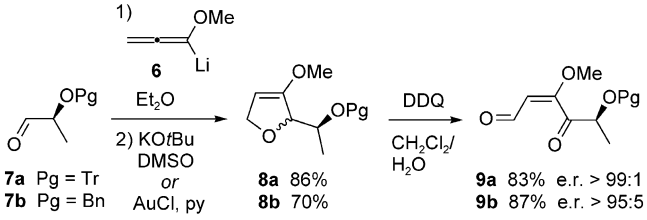


Scheme 1. Approach for the synthesis of deoxy sugars **1**–**4**.

Results and Discussion

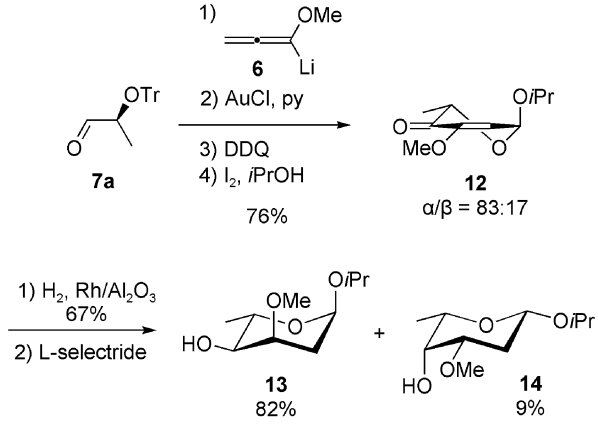
The preparation of trityl- and benzyl-protected keto aldehydes **9a** and **9b** is shown in Scheme 2: lithiated methoxyallene **6** was generated in situ by treatment of methoxyallene with *n*-butyllithium and subsequently lactaldehydes **7a**[10] and **7b**[11] were added to furnish the corresponding α-allenyl alcohols quantitatively. The 5-*endo*-*trig* cyclization of these intermediates was performed with KO*t*Bu in DMSO or, alternatively, using catalytic amounts of gold(I) chloride and pyridine,[6c] furnishing dihydrofurans **8a** and **8b** in high yields (*syn*/*anti* 30:70 in each case). Oxidative ring cleavage using two equivalents of DDQ provided enantiopure keto aldehydes **9a** and **9b**, without any indication of racemization.



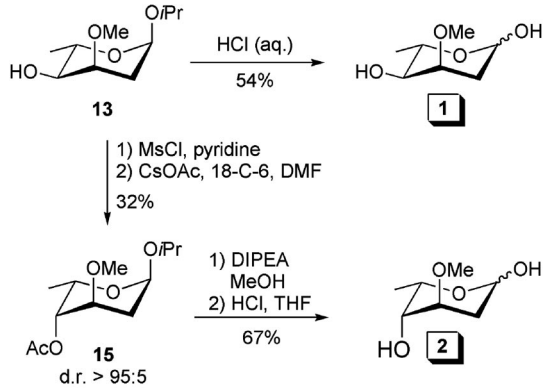
Scheme 2. Preparation of keto aldehydes **9a** and **9b**.

L-Cymarose and L-Sarmentose

ribo-Configured cymarose (**1**) and *xylo*-configured sarmentose (**2**) commonly feature an axial 3-*O*-methyl group while being epimeric at C-4. Thus, if the correct C-3 configuration could be installed via face-selective hydrogenation of the enol ether double bond prior to the reduction of the C-4 carbonyl group, both sugars may be derived from a single intermediate. The preparation of an adequate precursor to **1** and **2** is shown in Schemes 3 and 4. As we reported previously,[7b] keto aldehyde **9a** undergoes a clean detritylation with iodine in 2-propanol[12] and is concomitantly converted into α-configured pyranoside **12** with good anomeric selectivity. Compound **12**, which is also a suitable precursor for 4-aminohexoses, could be obtained in high yield and in gram quantities in four straightforward steps without purification of any intermediates. The use of gold(I) chloride as catalyst (5 mol-%) in the cyclization step makes this procedure even more convenient and efficient than the previously reported cyclization with KO*t*Bu in DMSO.[6a,6b] Hydrogenation of **12** proceeds with 1,3-*cis*-selectivity[13] and subsequent reduction of the carbonyl group with L-selectride provides *ribo*-configured pyranoside **13** with entire stereocontrol. As a byproduct, *lyxo*-configured pyranoside **14** was obtained and could be separated by column chromatography. Whereas hydrolysis of **13** leads to L-cymarose (**1**),[7b] it can alternatively be epimerized to acetate **15** by mesylation and S_N2 reaction with cesium acetate in the presence of 18-crown-6,[14] **15** being obtained in moderate overall yield.[15] Acetate deprotection and hydrolysis furnishes free L-sarmentose (**2**, Scheme 4).



Scheme 3. Synthesis of pyranosides **12**, **13** and **14**.



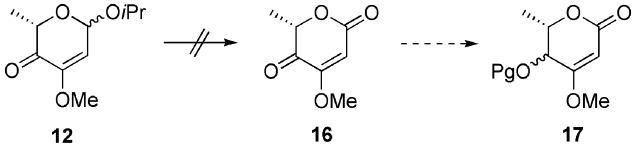
Scheme 4. Synthesis of L-cymarose (**1**) and L-sarmentose (**2**).

While the seven-step synthesis of cymarose (**1**) constitutes the shortest known route to this carbohydrate, the eleven-step sequence towards sarmentose (**2**) is just the second one yet to be reported.[3] The approach via enuloside **12** combined good stereocontrol in the reduction steps with minimal use of protecting groups, for both the *ribo* and the *xylo* case. Notably, by use of different alkoxyallenes, a range of alkoxy groups could be introduced at C-3 leading to various unnatural derivatives.

L-Diginose and L-Oleandrose

The shared feature of L-diginose (**3**) and L-oleandrose (**4**) is the equatorial 3-*O*-methyl group and analogously to the

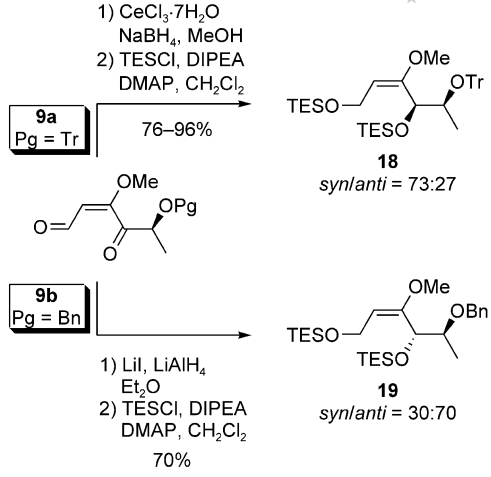
synthesis of cymarose and sarmentose, a directed hydrogenation of the enol ether double served to establish the common C-3 configuration. To this end, we planned to exploit the known 3,5-*cis*-selectivity in the heterogeneous hydrogenation of α,β-unsaturated δ-lactones of type **17** (Scheme 5).[16] However, all attempts to convert enuloside **12** directly into keto lactone **16** – a possible precursor to lactones **17** – were unsuccessful.



Scheme 5.

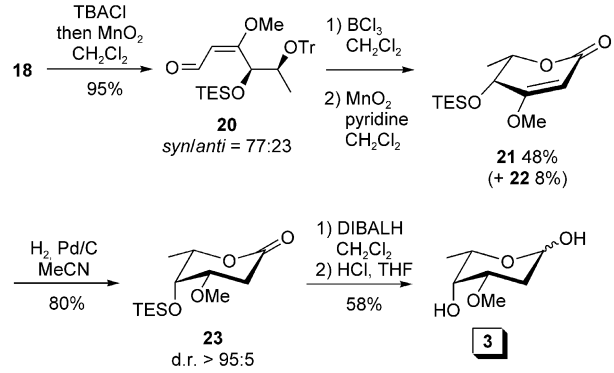
On the other hand, keto aldehydes **9a** and **9b** could be reduced to the corresponding diols in a stereodivergent fashion (Scheme 6): reduction of trityl-protected **9a** under Luche conditions[17] proceeds via the Felkin–Anh mode and silylation of the crude diol furnished bis(silyl ether) **18** with high yield and fair *syn*-selectivity. In turn, the chelation-controlled reduction of **9b** was more laborious. While zinc borohydride[18] offered perfect *anti*-selectivity (*syn*/*anti* = 1:99), side reactions led to a poor yield of only 30% after HPLC purification. The same lack of chemoselectivity was also observed with DIBALH/zinc iodide[19] and other reagent systems. Carrying out the reduction with lithium aluminum hydride and lithium iodide,[20] **19** could finally be obtained, after silylation, with good overall yield and acceptable *anti*-selectivity. Bis(silyl ether)s **18** and **19** were employed in subsequent reactions as mixtures of diastereomers as separation of the isomers was more easily achieved at later stages.

syn-Configured bis(silyl ether) **18** was elaborated into unsaturated lactone *threo*-**21** as shown in Scheme 7. Monodesilylation in the primary position, yet unfeasible in this case using TBAF or HF·pyridine complex, was achieved with TBACl at room temperature. Subsequent addition of manganese dioxide to the reaction mixture led to aldehyde **20** in excellent yield. To the best of our knowledge, this transformation represents the first example of a TES-deprotection under these exceptionally mild conditions. Next, tri-

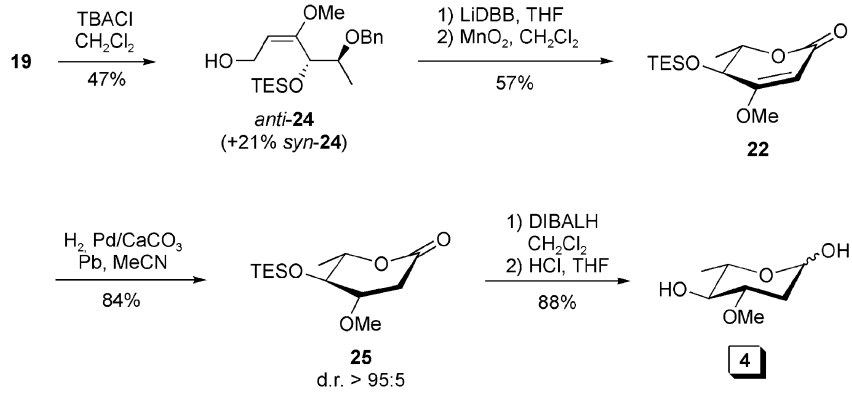


Scheme 6. Preparation of bis(silyl ether)s **18** and **19**.

tyl-deprotection was performed using BCl_3[21] at –78 °C and the very sensitive lactol thus generated was immediately subjected to another manganese dioxide oxidation to give δ-lactone **21** along with its diastereomer **22**, isomers being separable by column chromatography. Hydrogenation of **21** over Pd/C in acetonitrile left the TES group intact[22] and gave *lyxo*-configured lactone **23** exclusively. Reduction with DIBALH followed by acid-induced cleavage of the silyl group furnished L-diginose (**3**), in an 11-step sequence starting from lactaldehyde **7a**.



Scheme 7. Synthesis of L-diginose (**3**).



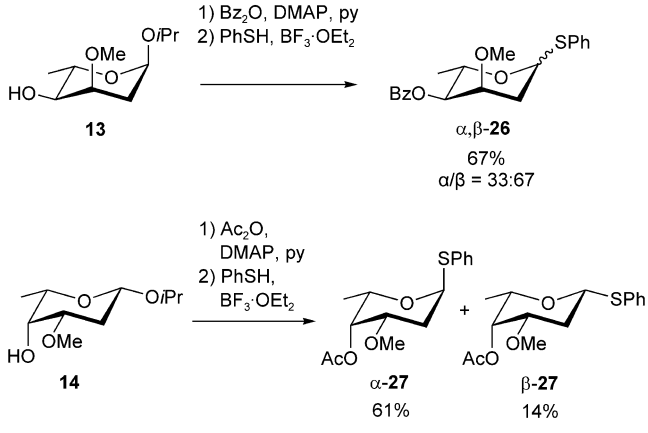
Scheme 8. Synthesis of L-oleandrose (**4**).

Similarly, *erythro*-configured lactone **22** could be accessed from bis(silyl ether) **19** (Scheme 8): TBACl-promoted mono-desilylation gave the readily separable allylic alcohols **24**. *anti*-**24** was debenzylated with LiDBB (lithium di-*tert*-butylbiphenyl)[23] and the diol obtained was oxidatively cyclized to lactone **22** with manganese dioxide. Hydrogenation of **22** with Lindlar's catalyst[16b] exclusively gave *arabino*-configured lactone **25**.[24] Reduction with DIBALH and desilylation with aqueous HCl led to L-oleandrose (**4**), thus also prepared in 11 steps overall from aldehyde **7b**.

Although our novel syntheses of L-diginose (**3**) and L-oleandrose (**4**) require 11 steps each, they are indeed compatible with those previously reported in terms of overall yield and efficiency.[3] While fair selectivities have been observed in the carbonyl reductions, excellent face discrimination was achieved in the hydrogenations of both lactones **21** and **22**. The latter case once more confirms previously made observations concerning the highly reliable 3,5-*cis*-selectivity in heterogeneous hydrogenations of *arabino*-configured substrates of this kind.[16d]

Glycosylation Reactions

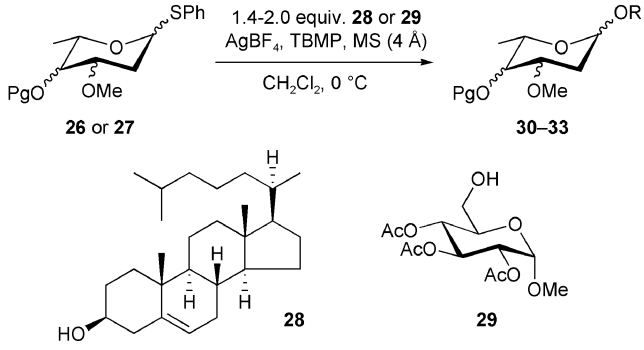
2-Deoxy glycosides are among the most abundant natural deoxy glycosides. The diastereoselectivity in glycosylations employing 2-deoxy glycosyl donors yet remains a substantial challenge.[25] This is due to the poor configurational stability of the newly formed anomeric bonds under (Lewis) acidic conditions, and especially, if 1,3-repulsive interactions with the aglycon occur as it is the case in the *ribo*-series. As shown in Scheme 9, we converted precursors to L-diginose and L-cymarose **13** and **14** into thiophenyl acetals **26** and **27**. Benzoylation of **13** and subsequent treatment with thiophenol and boron trifluoride–diethyl ether provided *ribo*-configured donor **26** as a mixture of anomers (α/β = 33:67). *lyxo*-Configured pyranoside **14** was acetylated and the intermediate acetate was converted into the readily separable thiophenyl donors α-**26** and β-**26**.[26]



Scheme 9. Preparation of thiophenyl donors **26** and **27**.

First results of glycosylations employing donors **26** and **27** with cholesterol (**28**) and methyl glucoside **29** as acceptors are summarized in Table 1.

Table 1. Glycosylation reactions of thiophenyl donors **26** and **27**.



Donor	Acceptor	Product, % yield	α/β
α,β-**26**	**28**	α,β-**30** (56)	67:33
α,β-**26**	**29**	α,β-**31** (69)	83:17
α-**27**	**28**	α-**32** (75)	> 95:5
β-**27**	**28**	α-**32** (77)	> 95:5
α-**27**	**29**	α-**33** (74)	> 95:5

Using silver(I) tetrafluoroborate along with 2,6-*tert*-butyl-4-methylpyridine (TBMP) as promoter system,[27] deoxy glycosides **30**–**33** were obtained in good yields. Thus, reaction of *ribo*-configured donor α,β-**26** with cholesterol gave glycoside α,β-**30** in 56% yield as a 2:1 mixture of anomers (α/β = 67:33). The reaction of α,β-**26** with methyl glucoside **29** leading to glycoside α,β-**31** proceeded with slightly better stereocontrol and gave the α-anomer with 5:1 selectivity (α/β = 83:17). With *lyxo*-configured donors α- and β-**27**, complete α-selectivity was observed in all cases and yields were generally higher. Reaction of α-**27** with cholesterol (**28**) as acceptor provided glycoside α-**32** in 75% yield. Glycosylation of β-**27** with **28** similarly was entirely α-selective. This clearly indicates an S_N1 type reaction mechanism and suggests that anomeric mixtures of thiophenyl donors, as α,β-**26** would react to a single product in a stereoconvergent fashion. Finally, reaction of α-**27** with methyl glucoside **29** provided glycoside α-**33** in 74% yield.

In light of the glycosylation of the heliquinomycin aglycon (Figure 1), the results obtained with cymarosyl donor α,β-**26** are promising, but further improvements need to be made in future experiments. The moderate α-selectivities we observed can be attributed to the axial methoxy group at C-3, which destabilizes the α-glycosides by 1,3-diaxial interaction and hence leads to the formation of anomeric mixtures.

Conclusions

We developed stereodivergent and robust routes to the four 2,6-dideoxyhexoses **1**–**4** combining two C_3 building blocks starting from lactaldehydes **7** and lithiated methoxyallene **6**. Again, the high utility of the alkoxyallene methodology in the synthesis of natural products has been demonstrated,[5] the 7-step preparation of L-cymarose (**1**) being a particularly efficient showcase application. The routes described have potential to be applied to the synthe-

sis of unnatural analogues bearing various alkoxy groups in the 3-position of the 2-deoxy carbohydrates as well as the introduction of amino groups at C-3 and C-4 providing unnatural amino deoxyhexoses. Preliminary experiments on the 2-deoxy-glycosylation of *ribo*- and *xylo*-configured thiophenyl glycosyl donors **26** and **27** showed promising yields and selectivities, while further investigations have to be carried out for the glycosylation of L-cymarose and the heliquinomycin aglycon.

Experimental Section

This section contains experimental procedures for key transformations. For full detail, please refer to the Supporting Information.

General Methods: Reactions were generally performed under argon in flame-dried flasks. Solvents and reagents were added by syringes. Solvents were dried using standard procedures. Commercial reagents were used as received without further purification unless otherwise stated. Products were purified by flash chromatography on silica gel (230–400 mesh, Merck or Fluka) or HPLC (Nucleosil 50–5). Unless otherwise stated, yields refer to analytically pure samples. NMR spectra were recorded with Bruker (AC 500) and JOEL (Eclipse 500) instruments. Chemical shifts in ppm are reported relative to the following resonances: $\delta(^1H) = 2.49$ (DMSO), 3.35 (CH_3OH), 4.79 (H_2O), 7.25 ($CHCl_3$) and $\delta(^{13}C) = 39.7$ ([D_6]-DMSO), 49.3 (CD_3OD), 77.0 ($CDCl_3$). ^{13}C NMR spectra in D_2O were referenced with $SiMe_4$ as external standard. Integrals are in accordance with assignments; coupling constants are given in Hz. All ^{13}C spectra are proton-decoupled. For detailed peak assignments 2D spectra were measured (COSY, HMQC, HMBC, NOESY and NOE if necessary). IR spectra were measured with a Nicolet 5 SXC FT-IR spectrometer equipped with a DTGS detector or with a Nicolet Avator 320FT IR spectrometer. MS and HRMS analyses were performed with Finnigan MAT 711 (EI, 80 eV, 8 kV), MAT CH7A (EI, 80 eV, 3 kV) and Varian Ionspec QFT-7 (ESI-FT ICRMS) instruments. Elemental analyses were carried out with CHN-Analyzer 2400 (Perkin–Elmer), Vario EL or Vario EL III. Melting points were measured with a Reichert apparatus Thermovar and are uncorrected. Optical rotation values were measured with Perkin–Elmer 241-P and IBZ Polar-LμP polarimeters at $\lambda = 589$ nm (sodium D emission).

Preparation of Pyranoside 12

Isopropyl 2,6-Dideoxy-3-*O*-methyl-α-L-*glycero*-hex-2-enopyranoside-4-ulose (α-12) and Isopropyl 2,6-Dideoxy-3-*O*-methyl-β-L-*glycero*-hex-2-enopyranoside-4-ulose (β-12): Methoxyallene[28] (5.30 mL, 4.45 g, 63.5 mmol) was dissolved in Et_2O (100 mL) at –50 °C and *n*BuLi (23.0 mL, 2.50 M in hexane, 57.5 mmol) was added slowly. The solution was stirred for 20 min and then cooled to –78 °C followed by the addition of a solution of lactaldehyde **7a**[10] (5.79 g, 18.3 mmol) in Et_2O (65 mL) over 15 min. The mixture was stirred at –78 °C for 5 h, then H_2O (100 mL) was added and the reaction was warmed to room temp. The layers were separated and the aqueous layer was extracted with Et_2O (3 ×). The combined organic layers were dried with $MgSO_4$, filtered, concentrated to dryness and the crude allenyl alcohol (yellow oil, 7.18 g, quant., *syn*/*anti* = 30:70)[29] was dried in vacuo. ***anti*-Isomer:** ^1H NMR (500 MHz, $CDCl_3$): $\delta = 1.03$ (d, $J = 6.3$ Hz, 3 H, 1-H), 2.25 (d, $J = 4.9$ Hz, 1 H, OH), 3.28 (s, 3 H, OMe), 3.55 (m_c, 1 H, 3-H), 3.83 (dq, $J = 3.5$, 6.3 Hz, 1 H, 2-H), 5.49–5.55 (m, 2 H, 6-H), 7.20–7.31, 7.46–7.53 (2 m, 15 H, Ph) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): $\delta =$ 15.6 (q, C-1), 55.9 (q, OMe), 71.5 (d, C-2), 74.5 (d, C-3), 87.1 (s, CPh_3), 92.6 (t, C-6), 127.0, 127.7, 128.9 (3d, Ph), 134.4 (s, C-4), 144.8 (s, Ph), 197.9 (s, C-5) ppm. ***syn*-Isomer:** ^1H NMR (500 MHz, $CDCl_3$): $\delta = 0.91$ (d, $J = 6.3$ Hz, 3 H, 1-H), 2.57 (d, $J = 7.1$ Hz, 1 H, OH), 3.58–3.61 (m, 1 H, 2-H), 3.95 (m_c, 1 H, 3-H), 7.20–7.31, 7.46–7.53 (2m, 15 H, Ph) ppm, missing signals could not be located. ^{13}C NMR (126 MHz, $CDCl_3$): $\delta = 15.2$ (q, C-1), 56.0 (q, OMe), 71.2 (d, C-2), 72.0 (d, C-3), 86.7 (s, CPh_3), 92.4 (t, C-6), 127.0, 127.6, 129.0 (3d, Ph), 134.3 (s, C-4), 144.9 (s, Ph), 198.4 (s, C-5) ppm.

The crude allenyl alcohol (7.18 g, max. 18.3 mmol) was dissolved in CH_2Cl_2 (270 mL) and pyridine (0.22 mL, 0.21 g, 2.70 mmol). AuCl (0.21 g, 0.90 mmol) was added and the mixture was stirred at room temp. for 30 min, conversion being monitored by TLC. H_2O (14 mL) was added to the mixture followed by DDQ (8.33 g, 36.7 mmol) and stirring was continued for 2 h. After addition of $NaHCO_3$ aq. and H_2O, the layers were separated and the aqueous layer was extracted with CH_2Cl_2 (3 ×). The combined organic layers were dried with $MgSO_4$, filtered, concentrated and the solution of the crude product was filtered through a 1 cm pad of silica gel, then evaporated to dryness to afford 6.56 g of the crude keto aldehyde **9a**. An analytical sample could be obtained by column chromatography (silica gel, EtOAc/hexanes = 1:3 → 1:1) and chiral HPLC analysis with a racemic reference sample showed e.r. > 99:1 (Chiralpak AD column, Daicel Chemical Industries Ltd., *n*-hexane/*i*PrOH = 100:0 → 98:2 over 40 min, flow 1 mL/min, 18 bar, retention times: (*R*)-enantiomer 23.1 min, (*S*)-enantiomer 33.6 min, detection: UV, $\lambda = 254$ nm). Yellow solid, m.p. 119–121 °C. $[\alpha]_D^{22} =$ –122.7 ($c = 1.51$, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$): $\delta = 1.41$ (d, $J = 6.7$ Hz, 3 H, 6-H), 3.58 (s, 3 H, OMe), 4.80 (q, $J = 6.7$ Hz, 1 H, 5-H), 5.20 (d, $J = 7.0$ Hz, 1 H, 2-H), 7.20–7.29, 7.44–7.47 (2m, 15 H, Ph), 9.45 (d, $J = 7.0$ Hz, 1 H, 1-H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): $\delta = 19.2$ (q, C-6), 55.9 (q, OMe), 72.1 (d, C-5), 87.9 (s, CPh_3), 109.8 (d, C-2), 127.4, 128.0, 129.0 (3d, Ph) 143.9 (s, Ph), 164.6 (s, C-3), 191.6 (d, C-1), 197.6 (s, C-4) ppm. IR (KBr): $\tilde{\nu} = 3090–2900$ (=C–H, –C–H), 1725, 1660, 1600 (C=O, C=C) cm^{-1}. MS (EI, 140 °C): *m*/*z* (%) = 400 (< 1) $[M]^{+\cdot}$, 243 (100) $[CPh_3]^+$, 165 (39). $C_{26}H_{24}O_4$ (400.5): calcd. C 77.98, H 6.04; found C 77.80, H 5.80.

The crude keto aldehyde **9a** (6.56 g, max. 16.4 mmol) was dissolved in CH_2Cl_2 (40 mL) and $HC(OiPr)_3$ (6.25 g, 32.9 mmol). A solution of iodine (1.30 g, 5.12 mmol) in *i*PrOH (85 mL) was added and the mixture was stirred at 60 °C for 2.5 h. The mixture was poured onto a 1:1 mixture of $NaHCO_3$ aq. and $Na_2S_2O_3$ aq. and shaken. The layers were separated and the aqueous layer was extracted with CH_2Cl_2 (3 ×). The combined organic layers were dried with $MgSO_4$, filtered and the solvents evaporated. Column chromatography (silica gel, EtOAc/hexanes, 1:3) provided α,β-**12** (83:17) as a colorless solid (2.79 g, 76% overall). By HPLC separation, pure α-**12** could be obtained for analysis. **α-12:** Colorless solid, m.p. 47 °C. $[\alpha]_D^{22} = -42.4$ ($c = 0.25$, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$): $\delta = 1.23$, 1.27 (2d, $J = 6.2$ Hz, 2 × 3 H, *i*Pr), 1.41 (d, $J =$ 6.8 Hz, 3 H, 6-H), 3.64 (s, 3 H, OMe), 4.03 (sept, $J = 6.2$ Hz, 1 H, *i*Pr), 4.66 (q, $J = 6.8$ Hz, 1 H, 5-H), 5.46 (d, $J = 4.2$ Hz, 1 H, 1-H), 5.70 (d, $J = 4.2$ Hz, 1 H, 2-H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): $\delta = 15.4$ (q, C-6), 21.9, 23.2 (2q, *i*Pr), 54.9 (q, OMe), 70.49 (d, C-5), 70.54 (d, *i*Pr), 93.0 (d, C-1), 111.1 (d, C-2), 149.7 (s, C-3), 192.8 (s, C-4) ppm. **β-12:** ^1H NMR (500 MHz, $CDCl_3$): $\delta = 1.24$, 1.29 (2d, $J = 6.2$ Hz, 2 × 3 H, *i*Pr), 1.50 (d, $J = 6.7$ Hz, 3 H, 6-H), 3.65 (s, 3 H, OMe), 4.14 (sept, $J = 6.2$ Hz, 1 H, *i*Pr), 4.18 (dq, $J =$ 1.1, 6.7 Hz, 1 H, 5-H), 5.54 (dd, $J = 1.1$, 2.0 Hz, 1 H, 1-H), 5.75 (d, $J = 2.0$ Hz, 1 H, 2-H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): $\delta =$ 17.0 (q, C-6), 21.7, 23.5 (2q, *i*Pr), 55.0 (q, OMe), 70.6 (d, *i*Pr), 74.8 (d, C-5), 95.0 (d, C-1), 114.3 (d, C-2), 150.2 (s, C-3), 192.8 (s, C-4)

ppm. **α/β-12:** IR (film): ṽ = 3070–2840 (=C–H, –C–H), 1710, 1640 (C=O, C=C) cm^{-1}. MS (EI, 30 °C): *m/z* (%) = 200 (19) $[M]^{+\cdot}$, 158 (19), 141 (100) $[M - C_3H_7O]^+$, 114 (46), 71 (38), 57 (39). HRMS (EI, 30 °C): *m/z* calcd. for $[C_{10}H_{16}O_4]^{+\cdot}$: 200.1049, found 200.1052.

Two-Step Conversion of Pyranoside α/β-12 into 13 and 14

Rhodium on Al_2O_3 (5 wt.-% Rh, 637 mg, 0.31 mmol) was suspended in EtOAc (30 mL) under Ar and the suspension was saturated with H_2, via cannula, for 30 min. A solution of α/β-**12** (611 mg, 3.05 mmol, α/β = 83:17) in EtOAc (15 mL) was added and the mixture was stirred at 1 bar H_2-pressure and room temp. for 4.5 h. The mixture was filtered through Celite (with EtOAc), the filtrate was concentrated and chromatographed (EtOAc/hexanes = 1:2) to afford the intermediate saturated ketones (414 mg, 67%, α-*erythro*/β-*threo* = 81:19). HPLC separation provided the α-*erythro* product in pure form.

Isopropyl 2,6-Dideoxy-3-*O*-methyl-α-L-*erythro*-hexopyranoside-4-ulose:[7b] Yellowish solid; m.p. 44 °C. $[\alpha]_D^{22}$ = –252.1 (*c* = 0.36, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$): δ = 1.16, 1.20 (2d, *J* = 6.2 Hz, 2 × 3 H, *i*Pr), 1.33 (d, *J* = 7.0 Hz, 3 H, 6-H), 1.80 (ddd, *J* = 6.6, 13.1, 13.6 Hz, 1 H, 2-H^a), 2.68 (ddd, *J* = 6.6, 6.7, 13.6 Hz, 1 H, 2-H^b), 3.47 (s, 3 H, OMe), 3.94 (sept, *J* = 6.2 Hz, 1 H, *i*Pr), 4.09 (ddd, *J* = 0.7, 6.7, 13.1 Hz, 1 H, 3-H), 4.39 (q, *J* = 7.0 Hz, 1 H, 5-H), 5.19 (t, *J* = 6.6 Hz, 1 H, 1-H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 15.7 (q, C-6), 21.6, 23.5 (2q, *i*Pr), 34.1 (t, C-2), 58.2 (q, OMe), 69.2 (d, *i*Pr), 71.3 (d, C-5), 77.2 (d, C-3), 94.7 (d, C-1), 211.5 (s, C-4) ppm.

Isopropyl 2,6-Dideoxy-3-*O*-methyl-β-L-*threo*-hexopyranoside-4-ulose:[7b] ^1H NMR (500 MHz, $CDCl_3$): δ = 1.18, 1.23 (2d, *J* = 6.2 Hz, 2 × 3 H, *i*Pr), 1.25 (d, *J* = 6.5 Hz, 3 H, 6-H), 2.06 (dt, *J* = 3.6, 12.4 Hz, 1 H, 2-H^a), 2.47 (ddd, *J* = 1.5, 6.6, 12.4 Hz, 1 H, 2-H^b), 3.48 (s, 3 H, OMe), 3.95 (sept, *J* = 6.2 Hz, 1 H, *i*Pr), 4.22 (dd, *J* = 6.6, 12.4 Hz, 1 H, 3-H), 4.34 (q, *J* = 6.5 Hz, 1 H, 5-H), 5.10 (br. d, *J* = 3.6 Hz, 1 H, 1-H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 13.8 (q, C-6), 24.6, 23.2 (2q, *i*Pr), 40.0 (t, C-2), 58.3 (q, OMe), 69.3 (d, *i*Pr), 70.1 (d, C-5), 78.3 (d, C-3), 94.7 (d, C-1), 205.8 (s, C-4) ppm. Mixture of diastereomers: IR (KBr): ṽ = 2980–2830 (C–H), 1740 (C=O) cm^{-1}. MS (EI, 80 °C): *m/z* (%) = 202 (2) $[M]^{+\cdot}$, 174 (3) $[M - CO]^+$, 159 (2) $[M - C_3H_7]^+$, 143 (27) $[M - C_3H_7O]^+$, 130 (46), 103 (44), 72 (65), 59 (100) $[C_3H_7O]^+$. HRMS (EI, 80 °C): *m/z* calcd. for $[C_{10}H_{18}O_4]^{+\cdot}$: 202.1205, found 200.1212.

L-Selectride® (9.00 mL, 1.00 M in THF, 9.00 mmol) was added at –78 °C to the mixture of the above ketones (886 mg, 4.38 mmol) in THF (12 mL). The mixture was stirred at –78 °C for 6 h, then NH_4Cl aq. (10 mL) was added. After warming to room temp., H_2O was added and the layers were separated. The aqueous layer was extracted with EtOAc (3 ×) and the combined organic layers were dried with $MgSO_4$, filtered and concentrated. Column chromatography (silica gel, EtOAc/hexanes, 1:1) provided pyranosides **13** (R_F ≈ 0.30, 732 mg, 82%) and **14** (R_F ≈ 0.20, 79 mg, 9%). Due to the volatility of the products, vacuum drying was carried out at 0 °C.

Isopropyl 2,6-Dideoxy-3-*O*-methyl-α-L-*ribo*-hexopyranoside (13): Colorless liquid. $[\alpha]_D^{22}$ = –189.0 (*c* = 0.46, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$): δ = 1.09, 1.17 (2d, *J* = 6.2 Hz, 2 × 3 H, *i*Pr), 1.22 (d, *J* = 6.4 Hz, 3 H, 6-H), 1.70 (ddd, *J* = 3.6, 4.6, 14.7 Hz, 1 H, 2-H^a), 2.17 (ddd, *J* = 1.8, 3.6, 14.7 Hz, 1 H, 2-H^b), 2.58 (d, *J* = 9.5 Hz, 1 H, OH), 3.25 (dt, *J* = 3.6, 9.5 Hz, 1 H, 4-H), 3.38 (s, 3 H, OMe), 3.57 (q, *J* = 3.6 Hz, 1 H, 3-H), 3.81 (sept, *J* = 6.2 Hz, 1 H, *i*Pr), 3.93 (qd, *J* = 6.4, 9.5 Hz, 1 H, 5-H), 4.83 (dd, *J* = 1.8, 4.6 Hz, 1 H, 1-H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 17.8 (q, C-6), 21.5, 23.4 (2q, *i*Pr), 31.3 (t, C-2), 56.1 (q, OMe), 64.9 (d, C-5), 68.8 (d, *i*Pr), 72.3 (d, C-4), 74.9 (d, C-3), 94.0 (d, C-1) ppm. IR (film): ṽ = 3470 (OH), 2970–2830 (C–H) cm^{-1}. MS (pos. FAB): *m/z* (%) = 227 ($[M + Na]^+$, 7).

Isopropyl 2,6-Dideoxy-3-*O*-methyl-β-L-*lyxo*-hexopyranoside (14): $[\alpha]_D^{22}$ = –125.4 (*c* = 0.41, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$): δ = 1.11, 1.16 (2d, *J* = 6.2 Hz, 2 × 3 H, *i*Pr), 1.27 (d, *J* = 6.6 Hz, 3 H, 6-H), 1.80–1.84 (m, 2 H, 2-H), 2.13 (br. s, 1 H, OH), 3.37 (s, 3 H, OMe), 3.60–3.65 (m, 1 H, 3-H), 3.75–3.78 (m, 1 H, 4-H), 3.86 (sept, *J* = 6.2 Hz, 1 H, *i*Pr), 3.90 (br. dq, *J* = 0.7, 6.6 Hz, 1 H, 5-H), 5.00–5.02 (m, 1 H, 1-H) ppm, broadening of signals observed at 25 °C. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 16.8 (q, C-6), 21.3, 23.3 (2q, *i*Pr), 30.0 (t, C-2), 55.5 (q, OMe), 65.3 (d, C-5), 67.7 (d, C-4), 68.3 (d, *i*Pr), 74.7 (d, C-3), 95.2 (d, C-1) ppm.

2,6-Dideoxy-3-*O*-methyl-L-*ribo*-hexose (L-Cymarose, 1): Pyranoside **13** (61 mg, 298 μmol) was dissolved in THF (2 mL) and HCl (2 N aq., 0.30 mL) was added. After 23 h at room temp., the mixture was diluted with THF (8 mL) and Dowex Marathon A2 resin (OH^--form, 520 mg) was added. After 2 h of stirring, NaOH solution (5 N aq., 0.20 mL) was added and stirring was continued for another 2 h. The mixture was further diluted with THF (5 mL) and $MgSO_4$ was directly added, followed by filtration. The filtrate was concentrated and column chromatography (silica gel, 100% EtOAc) provided the product as an oil. The oil was repeatedly taken up with Et_2O and the solvents evaporated to dryness. Prolonged drying at 0.1 mbar furnished 26 mg (54%) of **1** as colorless needles. Analytical data see below.

Reduction of Keto Aldehydes 9a and 9b

(2*E*,4*R*,5*S*)-3-Methoxy-1,4-bis(triethylsiloxy)-5-trityloxyhex-2-ene (*syn*-18) and (2*E*,4*S*,5*S*)-3-Methoxy-1,4-bis(triethylsiloxy)-5-trityloxyhex-2-ene (*anti*-18): A solution of $CeCl_3 \cdot 7H_2O$ (13.9 g, 37.3 mmol) in MeOH (100 mL) was added at –78 °C to a solution of keto aldehyde **9a** (6.77 g, 16.9 mmol) in CH_2Cl_2 (120 mL). $NaBH_4$ (1.98 g, 52.4 mmol) was added and the mixture was stirred at –78 °C for 3 h. Then NH_4Cl aq. (50 mL) was added, and H_2O (500 mL) after warming to room temp. The layers were separated and the aqueous layer was extracted with CH_2Cl_2 (3 ×). The combined organic layers were dried with $MgSO_4$, filtered and concentrated. The crude foamy product (*syn*/*anti* = 73:27 by ^1H NMR) was dried in vacuo. The crude product (5.98 g, max. 14.8 mmol) was dissolved in CH_2Cl_2 (200 mL) and DMAP (0.40 g, 3.27 mmol), iPr_2NEt (8.00 mL, 5.80 g, 44.9 mmol) and TESCl (7.50 mL, 6.68 g, 44.3 mmol) were added. After 17 h of stirring at room temp., the mixture was poured onto $NaHCO_3$ aq., the layers were separated and the aqueous layer was extracted with CH_2Cl_2 (3 ×). The combined organic layers were dried with $MgSO_4$, filtered and concentrated. Column chromatography (silica gel, EtOAc/hexanes, 1:10) provided *syn*/*anti*-**18** (colorless oil, 8.17 g; 76% over 2 steps, *syn*/*anti* = 68:32) and HPLC separation furnished samples of the pure diastereomers. The yield of the reaction varies between 76–96%. ***syn*-18:** Colorless oil. $[\alpha]_D^{22}$ = –5.9 (*c* = 0.58, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$): δ = 0.48–0.54, 0.55 (m, q, *J* = 8.0 Hz, 2 × 6 H, $SiEt_3$), 0.59 (d, *J* = 6.2 Hz, 3 H, 6-H), 0.87, 0.93 (2t, *J* = 8.0 Hz, 18 H, $SiEt_3$), 3.48 (s, 3 H, OMe), 3.71 (quint, *J* = 6.2 Hz, 1 H, 5-H), 4.22–4.28 (m, 3 H, 4-H, 1-H), 4.63 (dd, *J* = 6.4, 7.3 Hz, 1 H, 2-H), 7.18–7.28, 7.51–7.54 (2m, 15 H, Ph) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 4.5, 4.6, 6.76, 6.79 (2t, 2 q, $SiEt_3$), 16.9 (q, C-6), 54.0 (q, OMe), 58.8 (t, C-1), 73.1 (d, C-5), 73.5 (d, C-4), 86.7 (s, CPh_3), 100.7 (d, C-2), 126.8, 127.4, 129.3 (3d, Ph), 145.4 (s, Ph), 156.6 (s, C-3) ppm. ***anti*-18:** Colorless oil. $[\alpha]_D^{22}$ = +11.8 (*c* = 1.08, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$): δ = 0.55–0.66 (m, 12 H, $SiEt_3$), 0.87 (d, *J* = 6.2 Hz, 3 H, 6-H), 0.90, 0.98 (2t, *J* = 7.9 Hz, 18 H, $SiEt_3$), 3.29 (s, 3 H, OMe), 3.52 (quint, *J* = 6.2 Hz, 1 H, 5-H), 4.25 (dd, *J* = 6.2, 12.0 Hz, 1 H, 1-H^a), 4.33 (dd, *J* = 7.7, 12.0 Hz, 1

H, 1-H^b), 4.36 (d, J = 6.2 Hz, 1 H, 4-H), 4.55 (dd, J = 6.2, 7.7 Hz, 1 H, 2-H), 7.16–7.26, 7.41–7.45 (2m, 15 H, Ph) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 4.5, 4.7, 6.4, 6.9 (2t, 2 q, $SiEt_3$), 18.3 (q, C-6), 53.9 (q, OMe), 58.5 (t, C-1), 72.2 (d, C-5), 73.6 (d, C-4), 86.4 (s, CPh_3), 99.9 (d, C-2), 126.7, 127.3, 129.2 (3d, Ph), 145.3 (s, Ph), 156.7 (s, C-3) ppm. ***syn*/*anti*-18:** IR (film): $\tilde{\nu}$ = 3090–2810 (=C–H, –C–H), 1660 (C=C) cm^{-1}. MS (pos. FAB): m/z (%) = 655 ([M + Na]$^+$, <1), 243 ([CPh_3]$^+$, 100), 165 (63), 115 ([$C_6H_{15}Si$]$^+$, 87). $C_{38}H_{56}O_4Si_2$ (633.0): calcd. C 72.10, H 8.92; found C 71.91, H 9.06.

(2*E*,4*S*,5*S*)-5-Benzyloxy-3-methoxy-1,4-bis(triethylsiloxy)hex-2-ene (*anti*-19) and (2*E*,4*R*,5*S*)-5-Benzyloxy-3-methoxy-1,4-bis(triethylsiloxy)hex-2-ene (*syn*-19): Keto aldehyde **9b** (0.99 g, 3.99 mmol) was dissolved in Et_2O (50 mL) and LiI (1.83 g, 13.7 mmol) was added at –25 °C, portionwise, with vigorous stirring. After 10 min, the mixture was cooled to –78 °C and $LiAlH_4$ (0.60 g, 15.8 mmol) was added. After 2.5 h at –78 °C, EtOAc (30 mL) was slowly added, then a concentrated aqueous solution of K_2CO_3 (4 mL). The mixture was warmed to room temp. and diluted with EtOAc (30 mL). $MgSO_4$ was directly added and the mixture was filtered through silica gel (with EtOAc). The filtrate was evaporated to dryness and the crude product (*syn*/*anti* = 30:70 by ^{1}H NMR) was dried in vacuo. The crude diol mixture (0.97 g) was dissolved in CH_2Cl_2 (50 mL) and DMAP (0.08 g, 0.65 mmol), *i*Pr_2NEt (2.00 mL, 1.45 g, 11.2 mmol) and TESCl (2.00 mL, 1.78 g, 11.8 mmol) were added. After 20 h of stirring at room temp., the mixture was poured onto $NaHCO_3$ aq., the layers were separated and the aqueous layer was extracted with CH_2Cl_2 (3 ×). The combined organic layers were dried with $MgSO_4$, filtered and concentrated. Column chromatography (silica gel, EtOAc/hexanes, 1:10) provided *syn*/*anti*-**19** (1.37 g; 71% over 2 steps, *syn*/*anti* = 30:70) and HPLC separation furnished samples of the pure diastereomers. ***anti*-19:** Colorless oil. $[\alpha]_D^{22}$ = –23.8 (c = 0.08, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.55–0.68 (m, 12 H, $SiEt_3$), 0.93, 0.97 (2t, J = 7.8, 8.1 Hz, 18 H, $SiEt_3$), 1.25 (d, J = 6.3 Hz, 3 H, 6-H), 3.51 (s, 3 H, OMe), 3.66 (qd, J = 6.3, 8.0 Hz, 1 H, 5-H), 4.19 (d, J = 8.0 Hz, 1 H, 4-H), 4.23 (dd, J = 5.6, 12.2 Hz, 1 H, 1-H^a), 4.39 (dd, J = 8.1, 12.2 Hz, 1 H, 1-H^b), 4.42, 4.48 (AB system, J_{AB} = 11.7 Hz, 2 × 1 H, CH_2Ph), 4.72 (dd, J = 5.6, 8.1 Hz, 1 H, 2-H), 7.22–7.32 (m, 5 H, Ph) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 4.4, 4.6, 6.7, 6.8 (2t, 2 q, $SiEt_3$), 17.1 (q, C-6), 54.1 (q, OMe), 58.5 (t, C-1), 71.5 (t, CH_2Ph), 72.5 (d, C-4), 76.3 (d, C-5), 100.6 (d, C-2), 127.3, 127.7, 128.1 (3d, Ph), 138.8 (s, Ph), 156.1 (s, C-3) ppm. ***syn*-19:** Colorless oil, $[\alpha]_D^{22}$ = –6.5 (c = 0.16, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.58–0.65 (m, 12 H, $SiEt_3$), 0.93, 0.96 (2t, J = 7.7, 8.1 Hz, 18 H, $SiEt_3$), 1.02 (d, J = 6.3 Hz, 3 H, 6-H), 3.50 (s, 3 H, OMe), 3.70 (qd, J = 6.3, 7.6 Hz, 1 H, 5-H), 4.23 (dd, J = 6.6, 12.1 Hz, 1 H, 1-H^a), 4.30 (d, J = 7.6 Hz, 1 H, 4-H), 4.33 (dd, J = 7.6, 12.1 Hz, 1 H, 1-H^b), 4.62, 4.73 (AB system, J_{AB} = 12.0 Hz, 2 × H, CH_2Ph), 4.65 (dd, J = 6.6, 7.6 Hz, 1 H, 2-H), 7.23–7.37 (m, 5 H, Ph) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 4.2, 4.4, 6.48, 6.54 (2t, 2 q, $SiEt_3$), 16.4 (q, C-6), 54.0 (q, OMe), 58.1 (t, C-1), 72.6 (t, CH_2Ph), 74.4 (d, C-4), 77.8 (d, C-5), 99.7 (d, C-2), 127.0, 127.4, 127.9 (3d, Ph), 139.1 (s, Ph), 156.7 (s, C-3) ppm. ***syn*/*anti*-19:** IR (film): $\tilde{\nu}$ = 3090–2830 (=C–H, –C–H), 1665 (C=C) cm^{-1}. MS (EI, 100 °C): m/z (%) = 480 (5) [M]$^{+\cdot}$, 345 (39) [M – $C_9H_{11}O$]$^+$, 241 (15), 214 (49), 171 (62) 115 (27) [$C_6H_{15}Si$]$^+$, 91 (100) [C_7H_7]$^+$. $C_{26}H_{48}O_4Si_2$ (480.8): calcd. C 64.95, H 10.06; found C 65.26, H 10.19.

TES-Deprotection with TBACl, Conversion of Bis(silyl ether) 18 into Aldehyde 20

(2*E*,4*R*,5*S*)-3-Methoxy-4-triethylsiloxy-5-trityloxyhex-2-enal (*syn*-20) and (2*E*,4*S*,5*S*)-3-Methoxy-4-triethylsiloxy-5-trityloxyhex-2-enal (*anti*-20): TBACl (5.59 g, 20.1 mmol) was suspended in THF (330 mL) and the mixture was stirred at room temp. for 1 h. At 0 °C, a solution of bis(silyl ether) *syn*/*anti*-**18** (4.31 g, 6.81 mmol, *syn*/*anti* = 68:32) in THF (25 mL) was added and the resulting mixture was stirred for 2 h at room temp., conversion being complete by TLC. Molecular sieves (4 Å, 1.36 g) and MnO_2 (29.8 g, 343 mmol) were added and the suspension was stirred at room temp. for 30 h, then filtered through Celite (with CH_2Cl_2) and concentrated in vacuo. Column chromatography (silica gel, EtOAc/hexanes, 1:4) provided aldehyde *syn*/*anti*-**20** as yellowish oil (3.34 g, 95%, *syn*/*anti* = 77:23). Samples of the pure diastereomers were obtained by HPLC separation. ***syn*-20:** Colorless oil. $[\alpha]_D^{22}$ = –22.9 (c = 0.18, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.42 (q, J = 8.0 Hz, 6 H, $SiEt_3$), 0.82 (t, J = 8.0 Hz, 9 H, $SiEt_3$), 0.90 (d, J = 6.3 Hz, 3 H, 6-H), 3.69 (s, 3 H, OMe), 3.81 (dq, J = 5.6, 6.3 Hz, 1 H, 5-H), 4.39 (d, J = 5.6 Hz, 1 H, 4-H), 5.45 (d, J = 7.7 Hz, 1 H, 2-H), 7.21–7.30, 7.45–7.49 (2m, 15 H, Ph), 9.83 (d, J = 7.7 Hz, 1 H, 1-H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 4.4, 6.6 (t, q, $SiEt_3$), 16.5 (q, C-6), 55.7 (q, OMe), 72.6 (d, C-5), 73.9 (d, C-4), 87.1 (s, CPh_3), 106.7 (d, C-2), 127.1, 127.6, 129.0 (3d, Ph), 144.7 (s, Ph), 177.2 (s, C-3), 191.6 (d, C-1) ppm. ***anti*-20:** Colorless solid, m.p. 124–126 °C. $[\alpha]_D^{22}$ = +69.2 (c = 0.56, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.54–0.59 (m, 6 H, $SiEt_3$), 0.89 (t, J = 8.1 Hz, 9 H, $SiEt_3$), 1.03 (d, J = 6.1 Hz, 3 H, 6-H), 3.49 (s, 3 H, OMe), 3.57 (qd, J = 6.1, 7.1 Hz, 1 H, 5-H), 4.60 (d, J = 7.1 Hz, 1 H, 4-H), 5.24 (d, J = 7.8 Hz, 1 H, 2-H), 7.19–7.27, 7.40–7.48 (2m, 15 H, Ph), 9.90 (d, J = 7.8 Hz, 1 H, 1-H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 4.6, 6.6 (t, q, $SiEt_3$), 18.6 (q, C-6), 55.7 (q, OMe), 73.3 (d, C-5), 75.6 (d, C-4), 86.7 (s, CPh_3), 105.8 (d, C-2), 127.0, 127.5, 128.9 (3d, Ph), 144.7 (s, Ph), 178.4 (s, C-3), 190.3 (d, C-1) ppm. ***syn*/*anti*-20:** IR (film): $\tilde{\nu}$ = 3090–2875 (=C–H, –C–H), 1660, 1610 (C=O, C=C) cm^{-1}. MS (EI, 130 °C): m/z (%) = 516 (<1) [M]$^{+\cdot}$, 243 (100) [CPh_3]$^+$, 165 (22). $C_{32}H_{40}O_4Si$ (516.7): calcd. C 74.38, H 7.80; found C 74.08, H 7.62.

Hydrogenation of Lactones 21 and 22

2,6-Dideoxy-3-*O*-methyl-4-triethylsiloxy-L-*lyxo*-hexono-1,5-lactone (23): Pd/C (10 wt.-% Pd, 222 mg, 0.21 mmol) was suspended, under Ar, in MeCN (7 mL) and the suspension was saturated with H_2 via a cannula for 30 min. A solution of lactone **21** (173 mg, 0.64 mmol) in MeCN (5 mL) was added and the mixture was vigorously stirred at 1 bar H_2 pressure and room temp. for 18 h. The mixture was filtered through Celite (with EtOAc), the filtrate was concentrated and chromatographed (silica gel, EtOAc/hexanes = 2:3) to provide lactone **23** (140 mg, 80%, dr > 95:5). Colorless solid; m.p. 31 °C. $[\alpha]_D^{22}$ = –30.6 (c = 0.31, $CHCl_3$). ^{1}H NMR (500 MHz, CD_3OD): δ = 0.73 (m$_c$, 6 H, $SiEt_3$), 1.04 (t, J = 8.0 Hz, 9 H, $SiEt_3$), 1.39 (d, J = 6.5 Hz, 3 H, 6-H), 2.55 (dd, J = 10.8, 17.7 Hz, 1 H, 2-H^{ax}), 2.85 (dd, J = 6.7, 17.7 Hz, 1 H, 2-H^{eq}), 3.42 (s, 3 H, OMe), 3.73 (ddd, J = 2.0, 6.7, 10.8 Hz, 1 H, 3-H), 4.16 (m$_c$, 1 H, 4-H), 4.46 (dq, J = 1.1, 6.5 Hz, 1 H, 5-H) ppm. ^{13}C NMR (126 MHz, CD_3OD): δ = 6.3, 7.5 (t, q, $SiEt_3$), 18.1 (q, C-6), 32.9 (t, C-2), 57.0 (q, OMe), 69.8 (d, C-4), 77.6 (d, C-3), 78.9 (d, C-5), 173.4 (s, C-1) ppm. IR (KBr): $\tilde{\nu}$ = 2995–2835 (C–H), 1720 (C=O) cm^{-1}. MS (pos. FAB): m/z (%) = 297 ([M + Na]$^+$, 50), 275 ([M + H]$^+$, 20), 245 ([M – C_2H_5]$^+$, 39), 87 (100). $C_{13}H_{26}O_4Si$ (274.4): calcd. C 56.90, H 9.55; found C 56.72, H 9.33.

2,6-Dideoxy-3-*O*-methyl-4-triethylsiloxy-L-*arabino*-hexono-1,5-lactone (25): Pd on $CaCO_3$ (5 wt.-% Pd, 3.5 wt.-% Pb, 653 mg, 0.31 mmol) was suspended, under Ar, in MeCN (15 mL) and the suspension was saturated with H_2 via a cannula for 30 min. A solution of lactone **22** (155 mg, 0.57 mmol) in MeCN (4 mL) was added and the mixture was vigorously stirred at 1 bar H_2-pressure and room temp. for 24 h. The mixture was filtered through Celite (with

EtOAc), the filtrate was concentrated and chromatographed (silica gel, EtOAc/hexanes = 1:3) to provide lactone **25** (132 mg, 84%, *dr* > 95:5) as a colorless oil as well as 10 mg of unreacted **22**. $[\alpha]_D^{22}$ = –36.9 (*c* = 0.13, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.61–0.70 (m, 6 H, $SiEt_3$), 0.97 (t, *J* = 8.0 Hz, 9 H, $SiEt_3$), 1.42 (d, *J* = 6.5 Hz, 3 H, 6-H), 2.70 (ddd, *J* = 0.7, 4.0, 16.6 Hz, 1 H, 2-H^{ax}), 2.85 (dd, *J* = 5.1, 16.6 Hz, 1 H, 2-H^{eq}), 3.35 (s, 3 H, OMe), 3.54 (ddd, *J* = 4.0, 4.1, 5.1 Hz, 1 H, 3-H), 3.57 (ddd, *J* = 0.7, 4.1, 7.7 Hz, 1 H, 4-H), 4.13 (qd, *J* = 6.5, 7.7 Hz, 1 H, 5-H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 4.8, 6.7 (t, q, $SiEt_3$), 18.5 (q, C-6), 32.7 (t, C-2), 56.5 (q, OMe), 74.6 (d, C-4), 77.6 (d, C-5), 79.8 (d, C-3), 170.0 (s, C-1) ppm. IR (film): $\tilde{\nu}$ = 2955–2830 (C–H), 1760 (C=O) cm^{-1}. MS (pos. FAB): *m*/*z* (%) = 297 ([M + Na]$^+$, 51), 275 ([M + H]$^+$, 72), 243 ([M – OCH_3]$^+$, 50), 87 (100). $C_{13}H_{26}O_4Si$ (274.4): calcd. C 56.90, H 9.55; found C 56.52, H 9.68.

Preparation of Glycoside 32

Methyl 4-*O*-Benzoyl-2,6-dideoxy-3-*O*-methyl-α-L-*ribo*-hexopyranosyl-(1→6)-2,3,4-tri-*O*-acetyl-α-D-glucopyranoside (α-31) and Methyl 4-*O*-Benzoyl-2,6-dideoxy-3-*O*-methyl-β-L-*ribo*-hexopyranosyl-(1→6)-2,3,4-tri-*O*-acetyl-α-D-glucopyranoside (β-31): Thiophenyl donor α,β-**26** (38 mg, purity 85%, 0.09 mmol, α/β = 33:67), methyl glucoside **29** (54 mg, 0.17 mmol) and TBMP (2,6-*tert*-butyl-4-methylpyridine, 26 mg, 0.13 mmol) were dissolved in CH_2Cl_2 (2 mL) and molecular sieves (powdered, 4 Å, 160 mg) were added. The resulting suspension was stirred for 1 h at room temp., then the reaction flask was protected from light and $AgBF_4$ (55 mg, 0.28 mmol) was added at 0 °C. The mixture was stirred at 0 °C for 3 h, then filtered through Celite (with EtOAc) and the (turbid) filtrate was concentrated in vacuo. Column chromatography (silica gel, EtOAc/hexanes, 1:1) provided β-**31** (colorless sticky oil, $R_F \approx 0.50$, 6 mg, 12%) and α-**31** (colorless sticky oil, $R_F \approx 0.40$, 29 mg, 57%), hence α/β = 83:17. **α-31:** $[\alpha]_D^{22}$ = +6.7 (*c* = 0.23, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.21 (d, *J* = 6.4 Hz, 3 H, 6′-H), 1.88 (ddd, *J* = 3.9, 4.3, 14.7 Hz, 1 H, 2′-H^a), 1.98, 2.01, 2.05 (3s, 3×3 H, OAc), 2.28 (ddd, *J* = 2.0, 3.9, 14.7 Hz, 1 H, 2′-H^b), 3.34, 3.41 (2s, 2×3 H, OMe), 3.44 (dd, *J* = 6.7, 11.5 Hz, 1 H, 6-H^a), 3.77 (dd, *J* = 1.9, 11.5 Hz, 1 H, 6-H^b), 3.83 (br. dt, *J* = 3.3, 3.9 Hz, 1 H, 3′-H), 3.97 (ddd, *J* = 1.9, 6.7, 10.3 Hz, 1 H, 5-H), 4.38 (qd, *J* = 6.4, 8.9 Hz, 1 H, 5′-H), 4.80 (dd, *J* = 2.0, 4.3 Hz, 1 H, 1′-H), 4.849 (dd, *J* = 3.3, 8.9 Hz, 1 H, 4′-H), 4.854 (dd, *J* = 3.6, 10.2 Hz, 1 H, 2-H), 4.93 (d, *J* = 3.6 Hz, 1 H, 1-H), 4.98 (dd, *J* = 9.4, 10.3 Hz, 1 H, 4-H), 5.46 (dd, *J* = 9.4, 10.2 Hz, 1 H, 3-H), 7.41–7.45, 7.53–7.57, 8.04–8.07 (3m, 2 H, 1 H, 2 H, OBz) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 17.5 (q, C-6′), 20.61, 20.64, 20.7 (3q, OAc), 31.8 (t, C-2′), 55.0, 57.2 (2q, OMe), 63.0 (d, C-5′), 66.3 (t, C-6), 68.8 (d, C-5), 69.2 (d, C-4), 70.3 (d, C-3), 70.9 (d, C-2), 73.5 (d, C-3′), 74.6 (d, C-4′), 96.4 (d, C-1), 97.0 (d, C-1′), 128.4, 129.8 (2d, OBz), 129.9 (s, OBz), 133.1 (d, OBz), 165.9 (s, OBz), 169.6, 170.0, 170.1 (3s, OAc) ppm. IR (film): $\tilde{\nu}$ = 3065–2845 (=C–H, –C–H), 1755, 1720 (C=O) cm^{-1}. MS (ESI-TOF): *m*/*z* (%) = 607 (13) [M + K]$^+$, 591 (100) [M + Na]$^+$. $C_{27}H_{36}O_{13}$ (568.6): calcd. C 57.04, H 6.38; found C 57.21, H 6.51. **β-31:** $[\alpha]_D^{22}$ = +80.6 (*c* = 0.85, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.23 (d, *J* = 6.4 Hz, 3 H, 6′-H), 1.75 (ddd, *J* = 2.7, 9.2, 13.8 Hz, 1 H, 2′-H^{ax}), 2.00, 2.01, 2.06 (3s, 3×3 H, OAc), 2.20 (ddd, *J* = 2.1, 4.4, 13.8 Hz, 1 H, 2′-H^{eq}), 3.37, 3.40 (2s, 2×3 H, OMe), 3.57 (dd, *J* = 2.4, 10.7 Hz, 1 H, 6-H^a), 3.91 (m$_c$, 1 H, 3′-H), 3.94 (ddd, *J* = 2.4, 4.9, 9.6 Hz, 1 H, 5-H), 3.97 (dd, *J* = 4.9, 10.7 Hz, 1 H, 6-H^b), 4.11 (qd, *J* = 6.4, 9.2 Hz, 1 H, 5′-H), 4.77 (dd, *J* = 3.0, 9.2 Hz, 1 H, 4′-H), 4.82 (dd, *J* = 2.1, 9.2 Hz, 1 H, 1′-H), 4.88 (dd, *J* = 3.7, 9.6 Hz, 1 H, 2-H), 4.94 (d, *J* = 3.7 Hz, 1 H, 1-H), 5.08 (t, *J* = 9.6 Hz, 1 H, 4-H), 5.46 (t, *J* = 9.6 Hz, 1 H, 3-H), 7.42–7.47, 7.55–7.59, 8.03–8.07 (3m, 2 H, 1 H, 2 H, OBz) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 18.1 (q, C-6′), 20.71, 20.73, 20.8 (3q, OAc), 34.6 (t, C-2′), 55.3, 58.2 (2q, OMe), 66.7 (t, C-6), 68.0 (d, C-5), 68.2 (d, C-5′), 69.2 (d, C-4), 70.4 (d, C-3), 70.9 (d, C-2), 74.7 (d, C-3′), 75.2 (d, C-4′), 96.6 (d, C-1), 97.9 (d, C-1′), 128.4, 129.7 (2d, OBz), 129.9 (s, OBz), 133.2 (d, OBz), 165.8 (s, OBz), 169.4, 170.1, 170.2 (3s, OAc) ppm.

Analytical Data of 2,6-Dideoxyhexoses 1–4: Information on the assignments of the furanose tautomers is given in the Supporting Information.

2,6-Dideoxy-3-*O*-methyl-L-*ribo*-hexose (L-Cymarose, 1): After equilibration in CD_3OD, the NMR spectra showed two pyranose tautomers (α-pyranose 8%, β-pyranose 50%; α/β = 14:86) and two furanose tautomers (α-furanose 20%, β-furanose 22%; α/β = 48:52). Colorless solid, m.p. 86–88 °C (lit.[30] 86–87 °C, D-enantiomer). $[\alpha]_D^{22}$ = –49.8 [*c* = 0.27, H_2O, equilibrated, lit.[3d] $[\alpha]_D^{25}$ = –51.5 (*c* = 0.33, H_2O)]. α-Pyranose: ^{1}H NMR (500 MHz, CD_3OD): δ = 1.22 (d*, 3 H, 6-H), 1.76 (ddd, *J* = 3.2, 4.0, 14.5 Hz, 1 H, 2-H^a), 2.17 (ddd, *J* = 2.1, 3.9, 14.5 Hz, 1 H, 2-H^b), 3.25 (dd, *J* = 3.2, 9.1 Hz, 1 H, 4-H), 3.47 (s, 3 H, OMe), 3.64 (dt, *J* = 3.2, 3.9 Hz, 1 H, 3-H), 4.08 (m$_c$, 1 H, 5-H), 5.03 (dd, *J* = 2.1, 4.0 Hz, 1 H, 1-H) ppm, *signal partially overlapped. ^{13}C NMR (126 MHz, CD_3OD): δ = 18.3 (q, C-6), 33.6 (t, C-2), 58.4 (q, OMe), 66.0 (d, C-5), 73.8 (d, C-4), 78.9 (d, C-3), 92.4 (d, C-1) ppm. β-Pyranose: ^{1}H NMR (500 MHz, CD_3OD): δ = 1.22 (d, *J* = 6.3 Hz, 3 H, 6-H), 1.49 (ddd, *J* = 2.6, 9.8, 14.0 Hz, 1 H, 2-H^{ax}), 2.21 (ddd, *J* = 2.0, 3.4, 14.0 Hz, 1 H, 2-H^{eq}), 3.15 (dd, *J* = 3.4, 9.6 Hz, 1 H, 4-H), 3.43 (s, 3 H, OMe), 3.59 (dt, *J* = 2.6, 3.4 Hz, 1 H, 3-H), 3.74 (dq, *J* = 6.3, 9.6 Hz, 1 H, 5-H), 4.94 (dd, *J* = 2.0, 9.8 Hz, 1 H, 1-H) ppm. ^{13}C NMR (126 MHz, CD_3OD): δ = 18.7 (q, C-6), 36.7 (t, C-2), 58.0 (q, OMe), 71.4 (d, C-5), 74.5 (d, C-4), 79.2 (d, C-3), 92.9 (d, C-1) ppm. α-Furanose: ^{1}H NMR (500 MHz, CD_3OD): δ = 1.18 (d, *J* = 6.4 Hz, 3 H, 6-H), 1.95 (dt, *J* = 1.4, 15.2 Hz, 1 H, 2-H^a), 2.11 (ddd, *J* = 5.4, 6.7, 15.2 Hz, 1 H, 2-H^b), 3.32 (s, 3 H, OMe), 3.67–3.70 (m, 1 H, 5-H), 3.91–3.94 (m, 2 H, 3-H, 4-H), 5.45 (dd, *J* = 1.4, 5.4 Hz, 1 H, 1-H) ppm. ^{13}C NMR (126 MHz, CD_3OD): δ = 19.3 (q, C-6), 40.0 (t, C-2), 57.1 (q, OMe), 68.5 (d, C-5), 82.1 (d, C-3), 88.9 (d, C-4), 99.6 (d, C-1) ppm. β-Furanose: ^{1}H NMR (500 MHz, CD_3OD): δ = 1.21 (d, *J* = 6.3 Hz, 3 H, 6-H), 2.04 (ddd, *J* = 3.8, 6.6, 13.6 Hz, 1 H, 2-H^a), 2.09 (ddd, *J* = 3.9, 5.3, 13.6 Hz, 1 H, 2-H^b), 3.30 (s, 3 H, OMe), 3.71–3.78 (m, 2 H, 4-H, 5-H), 4.05–4.09 (m, 1 H, 3-H), 5.49 (dd, *J* = 3.8, 5.3 Hz, 1 H, 1-H) ppm. ^{13}C NMR (126 MHz, CD_3OD): δ = 19.5 (q, C-6), 41.0 (t, C-2), 56.9 (q, OMe), 69.2 (d, C-5), 82.4 (d, C-3), 89.4 (d, C-4), 99.8 (d, C-1) ppm. The spectroscopic data for the pyranoses are in agreement with the literature.[31]

2,6-Dideoxy-3-*O*-methyl-L-*xylo*-hexose (L-Sarmentose, 2): After equilibration in CD_3OD, the NMR spectra show two pyranose tautomers (α-pyranose 13%, β-pyranose 81%; α/β = 14:86), the β-furanose (5%) as well as traces of the α-furanose and the open chain aldehyde (total ca. 1%). Colorless oil, $[\alpha]_D^{22}$ = –11.4 [*c* = 0.40, H_2O, equilibrated, lit.[32] $[\alpha]_D^{24}$ = –15.9 (*c* = 0.34, H_2O)]. α-Pyranose: ^{1}H NMR (500 MHz, CD_3OD): δ = 1.22 (d, *J* = 6.7 Hz, 3 H, 6-H), 1.79 (dddd, *J* = 1.1, 2.4, 3.7, 14.4 Hz, 1 H, 2-H^{eq}), 2.11 (ddd, *J* = 3.3, 4.0, 14.4 Hz, 1 H, 2-H^{ax}), 3.46 (s, 3 H, OMe), 3.54 (m$_c$, 1 H, 3-H), 4.30 (dq, *J* = 1.7, 6.7 Hz, 1 H, 5-H), 5.11 (m$_c$, 1 H, 1-H) ppm, the signal of 4-H could not be located. ^{13}C NMR (126 MHz, CD_3OD): δ = 16.9 (q, C-6), 30.7 (t, C-2), 57.8 (q, OMe), 64.4 (d, C-5), 69.4 (d, C-4), 79.4 (d, C-3), 92.8 (d, C-1) ppm. β-Pyranose: ^{1}H NMR (500 MHz, CD_3OD): δ = 1.25 (d, *J* = 6.6 Hz, 3 H, 6-H), 1.72 (ddd, *J* = 3.0, 9.9, 13.5 Hz, 1 H, 2-H^{ax}), 1.91 (m$_c$, 1 H, 2-H^{eq}), 3.38 (m$_c$, 1 H, 4-H), 3.42 (s, 3 H, OMe), 3.56 (q, *J* = 3.0 Hz, 1 H, 3-H), 3.92 (dq, *J* = 1.2, 6.6 Hz, 1 H, 5-H), 4.91 (dd, *J* = 2.2, 9.9 Hz, 1 H, 1-H) ppm. ^{13}C NMR (126 MHz, CD_3OD): δ = 17.2 (q, C-6),

33.3 (t, C-2), 57.5 (q, OMe), 68.4 (d, C-4), 71.0 (d, C-5), 80.6 (d, C-3), 93.8 (d, C-1) ppm. β-Furanose: ^{1}H NMR (500 MHz, CD_3OD): δ = 1.93 (m_c, 1 H, 2-H^a), 2.40 (ddd, J = 1.9, 5.7, 14.2 Hz, 1 H, 2-H^b), 3.31 (s, 3 H, OMe), 3.89 (dd, J = 3.9, 7.0 Hz, 1 H, 4-H), 3.99 (m_c, 1 H, 3-H), 5.59 (dd, J = 4.3, 5.7 Hz, 1 H, 1-H) ppm, the signals of 5-H and 6-H are covered and could not be located. ^{13}C NMR (126 MHz, CD_3OD): δ = 19.6 (q, C-6), 40.8 (t, C-2), 57.1 (q, OMe), 67.9 (d, C-5), 82.9 (d, C-3), 86.2 (d, C-4), 99.1 (d, C-1) ppm; signals of the α-furanose in the ^{1}H NMR spectrum: δ = 5.43 (dd, J = 1.8, 5.4 Hz, 1 H, 1-H) ppm; signals of the free aldehyde form: δ = 9.60 (d, J = 8.1 Hz, 1 H, CHO) ppm. The spectroscopic data correlate satisfyingly with the literature (^{1}H NMR: 200 MHz, D_2O;[3i] 300 MHz, $CDCl_3$ of *n*-butyl-2,6-dideoxy-3-*O*-methyl-β-DL-*xylo*-hexopyranoside[33]).

2,6-Dideoxy-3-*O*-methyl-L-*lyxo*-hexose (L-Diginose, 3): After equilibration in D_2O, the NMR spectra show two pyranose tautomers (α-pyranose 42%, β-pyranose 44%; α/β = 49:51) and two furanose tautomers (α-furanose 10%, β-furanose 4%; α/β = 71:29). Colorless solid, m.p. 83–85 °C (lit.[34] 81–87 °C). $[\alpha]_D^{22}$ = –66.0 [c = 0.10, H_2O, equilibrated, lit.[35] $[\alpha]_D^{25}$ = –63.2 (c = 0.10, H_2O)]. α-Pyranose: ^{1}H NMR (500 MHz, D_2O): δ = 1.20 (d, J = 6.7 Hz, 3 H, 6-H), 1.83 (ddd, J = 3.7, 12.1, 13.2 Hz, 1 H, 2-H^{ax}), 1.88 (tdd, J = 1.2, 5.2, 13.2 Hz, 1 H, 2-H^{eq}), 3.38 (s, 3 H, OMe), 3.75 (ddd, J = 2.8, 5.2, 12.1 Hz, 1 H, 3-H), 3.93 (m_c, 1 H, 4-H), 4.11 (br. q, J = 6.7 Hz, 1 H, 5-H), 5.35 (m_c, 1 H, 1-H) ppm. ^{13}C NMR (126 MHz, D_2O): δ = 16.3 (q, C-6), 29.7 (t, C-2), 55.1 (q, OMe), 66.5 (d, C-5), 67.0 (d, C-4), 74.2 (d, C-3), 91.5 (d, C-1) ppm. β-Pyranose: ^{1}H NMR (500 MHz, D_2O): δ = 1.24 (d, J = 6.3 Hz, 3 H, 6-H), 1.55 (dt, J = 10.0, 12.1 Hz, 1 H, 2-H^{ax}), 2.04 (dddd, J = 1.0, 2.3, 4.8, 12.1 Hz, 1 H, 2-H^{eq}), 3.38 (s, 3 H, OMe), 3.56 (ddd, J = 3.0, 4.8, 12.1 Hz, 1 H, 3-H), 3.63 (dq, J = 1.0, 6.3 Hz, 1 H, 5-H), 3.83 (m_c, 1 H, 4-H), 4.80 (dd, J = 2.3, 10.0 Hz, 1 H, 1-H) ppm. ^{13}C NMR (126 MHz, D_2O): δ = 16.1 (q, C-6), 32.6 (t, C-2), 54.9 (q, OMe), 65.9 (d, C-4), 70.9 (d, C-5), 77.3 (d, C-3), 93.8 (d, C-1) ppm. α-Furanose: ^{1}H NMR (500 MHz, D_2O): δ = 1.19 (d, J = 6.6 Hz, 3 H, 6-H), 2.02 (td, J = 1.3, 14.5 Hz, 1 H, 2-H^a), 2.22 (ddd, J = 5.4, 7.0, 14.5 Hz, 1 H, 2-H^b), 3.34 (s, 3 H, OMe), 3.78–3.82 (m, 1 H, 5-H), 3.95 (ddd, J = 1.3, 2.6, 7.0 Hz, 1 H, 3-H), 4.04 (dd, J = 2.6, 5.0 Hz, 1 H, 4-H), 5.58 (dd, J = 1.3, 5.4 Hz, 1 H, 1-H) ppm. ^{13}C NMR (126 MHz, D_2O): δ = 18.3 (q, C-6), 38.4 (t, C-2), 56.5 (q, OMe), 67.8 (d, C-5), 81.9 (d, C-3), 87.4 (d, C-4), 98.4 (d, C-1) ppm. β-Furanose: ^{1}H NMR (500 MHz, D_2O): δ = 2.13 (ddd, J = 4.2, 6.5, 14.1 Hz, 1 H, 2-H), 3.34 (s, 3 H, OMe), 5.59 (dd, J = 4.2, 5.1 Hz, 1 H, 1-H) ppm, missing signals could not be located. The spectroscopic data are in good agreement with the literature (^{1}H NMR, 200 MHz, D_2O,[3i] 500 MHz, $CDCl_3$ for the α-pyranose[31]).

2,6-Dideoxy-3-*O*-methyl-L-*arabino*-hexose (L-Oleandrose, 4): After equilibration in CD_3OD, the NMR spectra show two pyranose tautomers α/β = 61:39. Colorless oil. $[\alpha]_D^{22}$ = +9.7 [c = 0.50, H_2O, equilibrated, lit.[3u] $[\alpha]_D^{20}$ = +10.4 (c = 1.25, H_2O)]. α-Pyranose: ^{1}H NMR (500 MHz, CD_3OD): δ = 1.26 (d, J = 6.2 Hz, 3 H, 6-H), 1.48 (ddd, J = 3.6, 11.5, 12.9 Hz, 1 H, 2-H^{ax}), 2.25 (ddd, J = 1.4, 4.9, 12.9 Hz, 1 H, 2-H^{eq}), 3.05 (t, J = 9.2 Hz, 1 H, 4-H), 3.46 (s, 3 H, OMe), 3.55 (ddd, J = 4.9, 9.2, 11.5 Hz, 1 H, 3-H), 3.88 (dqd, J = 0.4, 6.2, 9.2 Hz, 1 H, 5-H), 5.27 (m_c, 1 H, 1-H) ppm. ^{13}C NMR (126 MHz, CD_3OD): δ = 18.7 (q, C-6), 36.7 (t, C-2), 57.7 (q, OMe), 69.1 (d, C-5), 78.1 (d, C-4), 79.5 (d, C-3), 92.9 (d, C-1) ppm. β-Pyranose: ^{1}H NMR (500 MHz, CD_3OD): δ = 1.31 (d, J = 6.2 Hz, 3 H, 6-H), 1.35 (ddd, J = 9.8, 11.6, 12.3 Hz, 1 H, 2-H^{ax}), 2.35 (ddd, J = 2.1, 4.9, 12.3 Hz, 1 H, 2-H^{eq}), 3.02 (t, J = 9.0 Hz, 1 H, 4-H), 3.24 (ddd, J = 4.9, 9.0, 11.6 Hz, 1 H, 3-H), 3.32 (qd, J = 6.2, 9.0 Hz, 1 H, 5-H), 3.47 (s, 3 H, OMe), 4.78 (dd, J = 2.1, 9.8 Hz, 1 H, 1-H) ppm. ^{13}C NMR (126 MHz, CD_3OD): δ = 18.6 (q, C-6), 38.9 (t, C-2), 57.6 (q, OMe), 73.6 (d, C-5), 77.3 (d, C-4), 82.1 (d, C-3), 95.2 (d, C-1) ppm. The spectroscopic data are in agreement with the literature.[3u]

Supporting Information (see also the footnote on the first page of this article): Full experimental details and spectroscopic data of all compounds not described in the printed version, copies of NMR spectra of all compounds.

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[1] a) J. F. Kennedy, C. A. White, *Bioactive Carbohydrates in Chemistry, Biochemistry and Biology*, Ellis Horwood Publishers, Chichester, **1983**; b) A. Kirschning, A. F.-W. Bechthold, J. Rohr, *Top. Curr. Chem.* **1997**, *188*, 1–84.

[2] a) S. Hanessian, *Total Synthesis of Natural Products: The "Chiron" Approach*, Pergamon Press, Oxford, **1983**; b) F. M. Hauser, S. R. Ellenberger, *Chem. Rev.* **1986**, *86*, 35–67; c) A. Zamojski, in: *Preparative Carbohydrate Chemistry* (Ed.: S. Hanessian), Dekker, New York, **1997**, 615–636; d) A. Kirschning, M. Jesberger, K.-U. Schöning, *Synthesis* **2001**, 507–540.

[3] Cymarose (**1**): a) D. A. Prins, *Helv. Chim. Acta* **1946**, *29*, 378–382; b) H. R. Bolliger, P. Ulrich, *Helv. Chim. Acta* **1952**, *35*, 93–98; c) J. S. Brimacombe, R. Hanna, M. S. Saeed, L. C. N. Tucker, *J. Chem. Soc. Perkin Trans. 1* **1982**, 2583–2587; d) K. Toshima, T. Yoshida, S. Mukaiyama, K. Tatsuta, *Carbohydr. Res.* **1991**, *222*, 173–188; e) W. R. Roush, R. J. Brown, *J. Org. Chem.* **1983**, *48*, 5093–5101; f) S. Hatakeyama, K. Sakurai, S. Takano, *Tetrahedron Lett.* **1986**, *27*, 4485–4488; g) X. Y. Zhao, M. Ono, H. Akita, Y. M. Chi, *Chin. Chem. Lett.* **2006**, *17*, 730–732. Sarmentose (**2**): h) H. Hauenstein, T. Reichstein, *Helv. Chim. Acta* **1955**, *38*, 446–455; i) P. Herzegh, I. Kovács, F. J. Sztaricskai, *Tetrahedron* **1991**, *47*, 1541–1546. Diginose (**3**): j) C. Tamm, T. Reichstein, *Helv. Chim. Acta* **1948**, *31*, 1630–1644; k) T. Mukaiyama, T. Yamada, K. Suzuki, *Chem. Lett.* **1983**, 5–8; l) T. Mukaiyama, K. Suzuki, T. Yamada, F. Tabusa, *Tetrahedron* **1990**, *46*, 265–276. Oleandrose (**4**): m) E. Vischer, T. Reichstein, *Helv. Chim. Acta* **1944**, *27*, 1332–1345; n) F. Blindenbacher, T. Reichstein, *Helv. Chim. Acta* **1948**, *31*, 2061–2064; o) J. Dornhagen, A. Klausener, J. Runsink, H. D. Scharf, *Liebigs Ann. Chem.* **1985**, 1838–1846; p) R. L. Tolman, L. H. Peterson, *Carbohydr. Res.* **1989**, *189*, 113–122; q) M. W. Bredenkamp, C. W. Holzapfel, F. Toerien, *Synth. Commun.* **1992**, *22*, 2459–2477; r) K. Koga, S. Yamada, M. Yoh, T. Mizoguchi, *Carbohydr. Res.* **1974**, *36*, C9–C11; s) P. G. M. Wuts, S. S. Bigelow, *J. Org. Chem.* **1983**, *48*, 3489–3493; t) M. J. Ford, S. V. Ley, *Synlett* **1990**, 771–772; u) S. V. Ley, A. Armstrong, D. Díez-Martin, M. J. Ford, P. Grice, J. G. Knight, H. C. Kolb, A. Madin, C. A. Marby, S. Mukherjee, A. N. Shaw, A. M. Z. Slawin, S. Vile, A. D. White, D. J. Williams, M. Woods, *J. Chem. Soc. Perkin Trans. 1* **1991**, 667–692.

[4] Review: C. Azap, M. Brasholz, S. Sörgel, H.-U. Reißig, *Eur. J. Org. Chem.* **2007**, 3801–3814.

[5] For comprehensive overviews, see: a) R. Zimmer, *Synthesis* **1993**, 165–178; b) R. Zimmer, H.-U. Reißig, in: *Modern Allene Chemistry* (Eds.: N. Krause, A. S. K. Hashmi), Wiley-VCH, Weinheim **2004**, vol. 1, p. 425–492; c) M. Brasholz, H.-U. Reißig, R. Zimmer, *Acc. Chem. Res.* **2009**, *42*, 45–56.

[6] a) S. Hoff, L. Brandsma, J. F. Arens, *Recl. Trav. Chim. Pays-Bas* **1969**, *88*, 609–619; b) S. Hormuth, H.-U. Reißig, *J. Org. Chem.* **1994**, *59*, 67–73; c) M. Brasholz, H.-U. Reißig, *Synlett* **2007**, 1294–1298.

[7] a) O. Flögel, H.-U. Reißig, *Eur. J. Org. Chem.* **2004**, 2797–2804; b) For further examples of this oxidative cleavage and for a

preliminary communication of part of the work presented here see: M. Brasholz, H.-U. Reißig, *Angew. Chem.* **2007**, *119*, 1659–1662; *Angew. Chem. Int. Ed.* **2007**, *46*, 1634–1637.
[8] O. Achmatowicz Jr., P. Bukowski, B. Szechner, Z. Zwierzchowska, A. Zamojki, *Tetrahedron* **1971**, *27*, 1973–1996.
[9] a) N. L. Holder, *Chem. Rev.* **1982**, *82*, 287–332; b) J. M. Harris, M. Li, J. G. Scott, G. A. O'Doherty, in: *Strategies and Tactics in Organic Synthesis* (Ed.: M. Harmata), Elsevier, London, **2004**, *5*, p. 221–253.
[10] K. Mori, H. Kikuchi, *Liebigs Ann. Chem.* **1989**, 963–967.
[11] a) C. Dubost, B. Leroy, I. E. Istvan, B. Tinant, J.-P. Declercq, J. Bryans, *Tetrahedron* **2004**, *60*, 7693–7704; b) A. K. Gosh, J.-H. Kim, *Org. Lett.* **2004**, *6*, 2725–2728.
[12] J. L. Wahlstrom, R. C. Ronald, *J. Org. Chem.* **1998**, *63*, 6021–6022.
[13] For related hydrogenations, see: a) T. Honda, Y. Kobayashi, M. Tsubuki, *Tetrahedron* **1993**, *49*, 1211–1222; b) O. Moradei, C. Du Mortier, A. Fernandéz Cirelli, J. Thiem, *J. Carbohydr. Chem.* **1995**, *14*, 525–532.
[14] X. Gao, D. G. Hall, *J. Am. Chem. Soc.* **2003**, *125*, 9308–9309.
[15] No side products have been isolated in this reaction.
[16] a) P. Rollin, P. Sinay, *Carbohydr. Res.* **1981**, *98*, 139–142; b) B. Bardili, H. Marschall-Weyerstahl, P. Weyerstahl, *Liebigs Ann. Chem.* **1985**, 275–300; c) D. A. Evans, D. M. Fitch, T. E. Smith, V. J. Cee, *J. Am. Chem. Soc.* **2000**, *122*, 10033–10046; d) S. Brandänge, M. Färnbäck, H. Leijonmarck, A. Sundin, *J. Am. Chem. Soc.* **2003**, *125*, 11942–11955.
[17] a) J.-L. Luche, *J. Am. Chem. Soc.* **1978**, *100*, 2226–2227; b) A. L. Gemal, J.-L. Luche, *J. Am. Chem. Soc.* **1981**, *103*, 5454–5459.
[18] W. J. Gensler, F. Johnson, A. D. B. Sloan, *J. Am. Chem. Soc.* **1960**, *82*, 6074–6081.
[19] G. Solladié, G. Hanquet, C. Rolland, *Tetrahedron Lett.* **1997**, *38*, 5847–5850.
[20] a) Y. Mori, M. Kuhara, A. Takeuchi, M. Suzuki, *Tetrahedron Lett.* **1988**, *29*, 5419–5422; b) C. Aïssa, R. Riveiros, J. Ragot, A. Fürstner, *J. Am. Chem. Soc.* **2003**, *125*, 15512–15520.
[21] G. B. Jones, G. Hynd, J. M. Wright, A. Sharma, *J. Org. Chem.* **2000**, *65*, 263–265.
[22] H. Sajiki, T. Ikawa, K. Hattori, K. Hirota, *Chem. Commun.* **2003**, 654–655.
[23] P. K. Freeman, L. L. Hutchinson, *J. Org. Chem.* **1980**, *45*, 1924–1930.
[24] a) For an account dealing with the preferred conformation of compounds analogous to *arabino*-configured lactone **22**, please refer to ref. 16d; b) According to ^{1}H NMR, saturated lactone **25** should rather be represented in a boat-like conformation than in $^1C_4$ form. This is in agreement with NMR spectroscopic data previously reported for related systems: J. S. D. Kumar, F.-Y. Dupradeau, M. J. Strouse, M. E. Phelps, T. Toyokuni, *J. Org. Chem.* **2001**, *66*, 3220–3223.
[25] a) J. Thiem, W. Klaffke, *Top. Curr. Chem.* **1990**, *154*, 285–332; b) C. H. Marzabadi, R. W. Franck, *Tetrahedron* **2000**, *56*, 8385–8417.
[26] G. Zhang, L. Fang, L. Zhu, J. E. Aimiuwu, J. Shen, H. Cheng, M. T. Muller, G. E. Lee, D. Sun, P. G. Wang, *J. Med. Chem.* **2005**, *48*, 5269–5278.
[27] M. Lear, F. Yoshimura, M. Hirama, *Angew. Chem.* **2001**, *113*, 972–975; *Angew. Chem. Int. Ed.* **2001**, *40*, 946–949.
[28] M. Pérez, P. Canoa, G. Gómez, M. Teijeira, Y. Fall, *Synthesis* **2005**, 411–414.
[29] Assignment of the diastereomers was based on NMR and made according to the literature: B. Landmann, R. W. Hoffmann, *Chem. Ber.* **1987**, *120*, 331–333.
[30] S. Tsukamoto, K. Hayashi, H. Mitsuhashi, *Tetrahedron* **1985**, *41*, 927–934.
[31] H. Bai, W. Li, K. Koike, T. Satou, Y. Chen, T. Nikaido, *Tetrahedron* **2005**, *61*, 5797–5811.
[32] F. Abe, M. Hirowaka, T. Yamauchi, K. Honda, N. Hayashi, R. Nishida, *Chem. Pharm. Bull.* **1999**, *40*, 1384–1387.
[33] R. S. Coleman, J. R. Fraser, *J. Org. Chem.* **1993**, *58*, 385–392.
[34] K. Stöckel, W. Stöcklin, T. Reichstein, *Helv. Chim. Acta* **1969**, *52*, 1175–1202.
[35] G. Krishna, G. V. Shinde, M. S. Shingare, A. Khare, P. Maheshwari, *Phytochemistry* **1990**, *29*, 2961–2964.

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