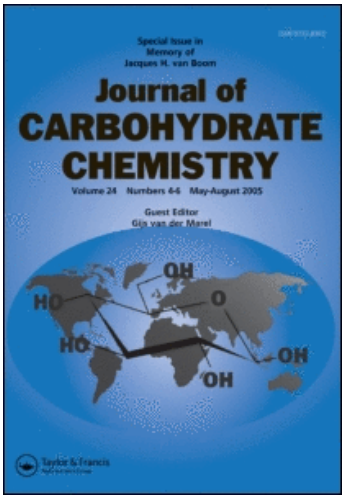


Journal of Carbohydrate Chemistry

Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713617200

Stereoselective Palladium(0)-Mediated Synthesis of Unsaturated 1,4-Disaccharides

Isabelle Frappa[a]; Boguslaw Kryczka[b]; Paul Lhoste[a]; Stanislaw Porwanski[ab]; Denis Sinou[a]
[a] Laboratoire de Synthèse Asymétrique, associé au CNRS, CPE Lyon, Université Claude, Villeurbanne, France [b] Department of Organic and Applied Chemistry, University of Lodz, Lodz, Poland

To cite this Article Frappa, Isabelle , Kryczka, Boguslaw , Lhoste, Paul , Porwanski, Stanislaw and Sinou, Denis(1997) 'Stereoselective Palladium(0)-Mediated Synthesis of Unsaturated 1,4-Disaccharides', Journal of Carbohydrate Chemistry, 16: 6, 891 — 910
To link to this Article: DOI: 10.1080/07328309708006546
URL: http://dx.doi.org/10.1080/07328309708006546

J. CARBOHYDRATE CHEMISTRY, 16(6), 891-910 (1997)

STEREOSELECTIVE PALLADIUM(0)-MEDIATED SYNTHESIS OF UNSATURATED 1,4-DISACCHARIDES

Isabelle Frappa,[a] Boguslaw Kryczka,[b] Paul Lhoste,[a] Stanislaw Porwanski[a,b] and Denis Sinou[a]*

[a] Laboratoire de Synthèse Asymétrique, associé au CNRS, CPE Lyon, Université Claude Bernard Lyon I, 43, boulevard du 11 Novembre 1918, 69622 Villeurbanne Cédex, France

[b] Department of Organic and Applied Chemistry, University of Lodz, ul. Naturowicsa 68, 90-136 Lodz, Poland

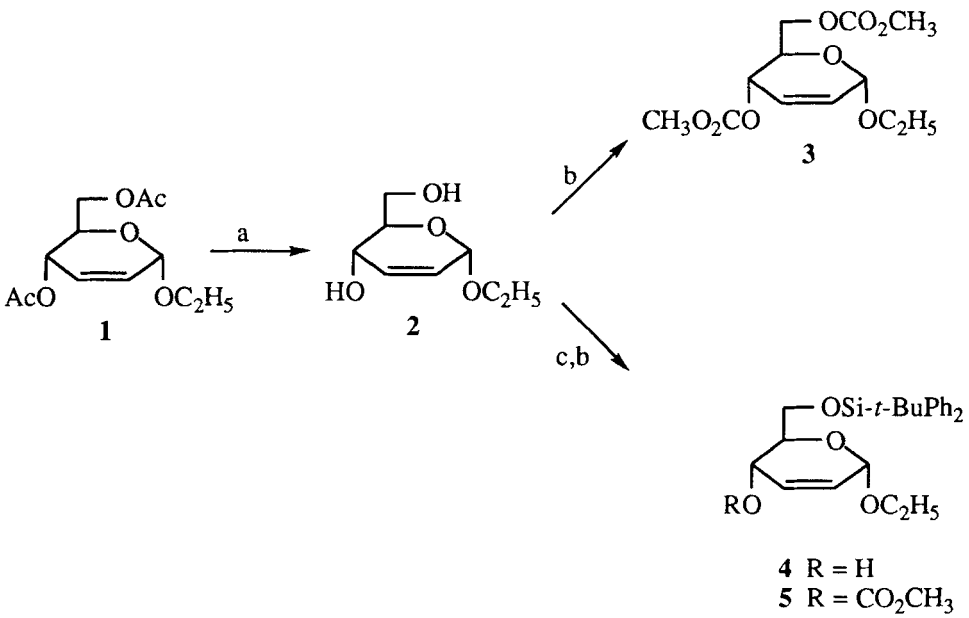
Received November 4, 1996 - Final Form April 1, 1997

ABSTRACT

Unsaturated 1,4-disaccharides are obtained in quite good yields by alkylation of ethyl α-*O*-Δ2-glycosides, having a leaving group at C-4, with various 1-hydroxy-carbohydrates in the presence of a catalytic amount of palladium(0). The reaction is regio- and stereospecific for α-*erythro* enosides **3** and **5**, and only stereospecific in the case of the β-*threo* enoside **7**, alkylation occuring at C-4 and C-2 in this case.

INTRODUCTION

Stereoselective glycosylation reaction is one of the most important problems in synthetic carbohydrate chemistry. Since the historical Kœnigs-Knorr synthesis, new methodologies have been directed towards the efficiency of this reaction (high chemical yield, regio- and stereoselectivity).[1] Although unsaturated disaccharides have been known since 1934, there are only a few methods for the synthesis of these compounds.[2] Unsaturated disaccharides were synthezised via a Ferrier reaction between 3,4,6-tri-*O*-acetyl-D-glycal and 1-hydroxycarbohydrates,[3] by sulfonamidoglycosylation of a glycal,[4] via 3-pentenosyl glycals,[5] or by glycosylation of unsaturated thioglycosides in the presence of $PdCl_2(CH_3CN)_2$.[6]



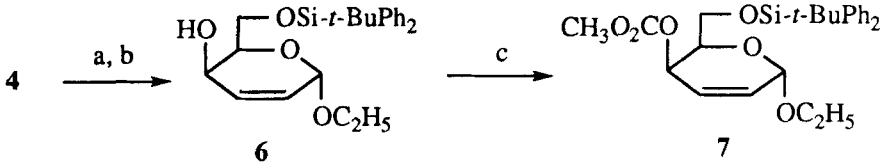
Reagents: a: CH_3ONa, CH_3OH; b: $ClCO_2CH_3$, pyridine; c: t-$BuPh_2SiCl$, NEt_3.

Scheme 1

Following our continuing interest in the formation of a carbon-oxygen bond catalysed by palladium(0) complexes and particularly the use of this very mild methodology in carbohydrate chemistry,[7] we presented recently a preliminary communication concerning the synthesis of unsaturated disaccharides catalysed by palladium(0).[8] This reaction was based on the direct anomeric *O*-alkylation of pyranoses and furanoses, and there are few examples on the use of this methodology in complex saccharide synthesis.[9] We reported in this paper a more detailed study on this reaction.

RESULTS AND DISCUSSION

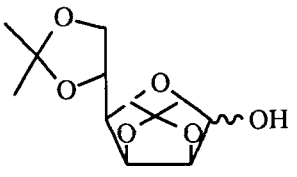
In our study, we expected that the reaction of a carbohydrate having a free anomeric hydroxyl group on a π-allyl palladium complex obtained by reacting palladium(0) with an appropriate unsaturated sugar possessing a good leaving group at the allylic position could lead to the formation of an unsaturated disaccharide. We choose for our study the unsaturated carbohydrates **3** and **5** easily prepared from ethyl 4,6-di-*O*-acetyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (**1**).[3]



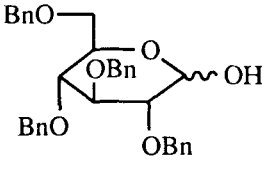
Reagents: a: $ClCH_2CO_2H$, DEAD, PPh_3; b: CH_3ONa, CH_3OH; c: $ClCO_2CH_3$, pyridine.

Scheme 2

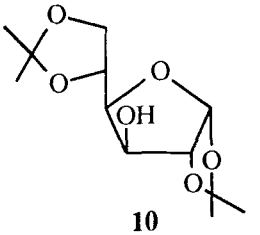
Deacetylation of compound **1** with sodium methanolate in methanol (Zemplèn procedure[10]) gave quantitatively the diol **2** (Scheme 1). Treatment of **2** with methyl chloroformate in pyridine afforded the dicarbonate **3** in 82 % yield. On the other hand, monosilylation of **2** followed by treatment with methyl chloroformate gave the monocarbonate **5** in 68 % yield. The *threo* derivative **7** was obtained from **4** by inversion of the configuration at C-4 (29 % yield) followed by reaction with methyl chloroformate (96 % yield) (Scheme 2). The reaction of these unsaturated carbohydrates **3**, **5** and **7** with various 1-hydroxy sugars **8**, **9**, **11** and **12** as well as with 1,2;5,6-di-*O*-isopropylidene-α-D-glucofuranose (**10**) was performed in tetrahydrofuran at 60 °C in the presence of a catalytic amount of tris(dibenzylideneacetone)dipalladium or $Pd_2(dba)_3$ and 1,4-bis(diphenylphosphino)butane or dppb.



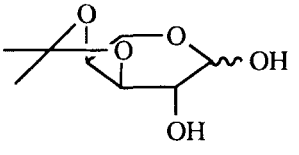
8



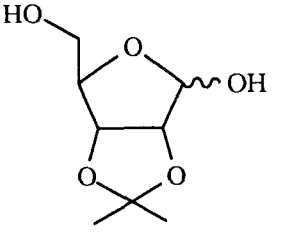
9



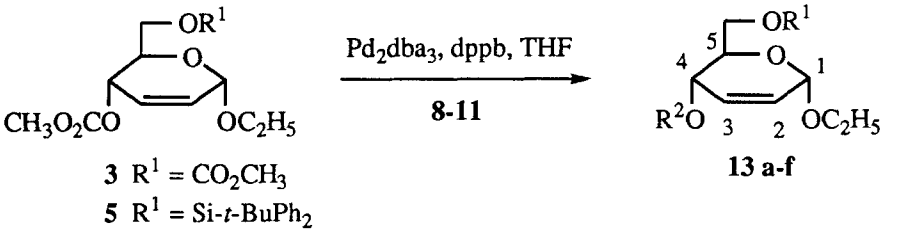
10



11

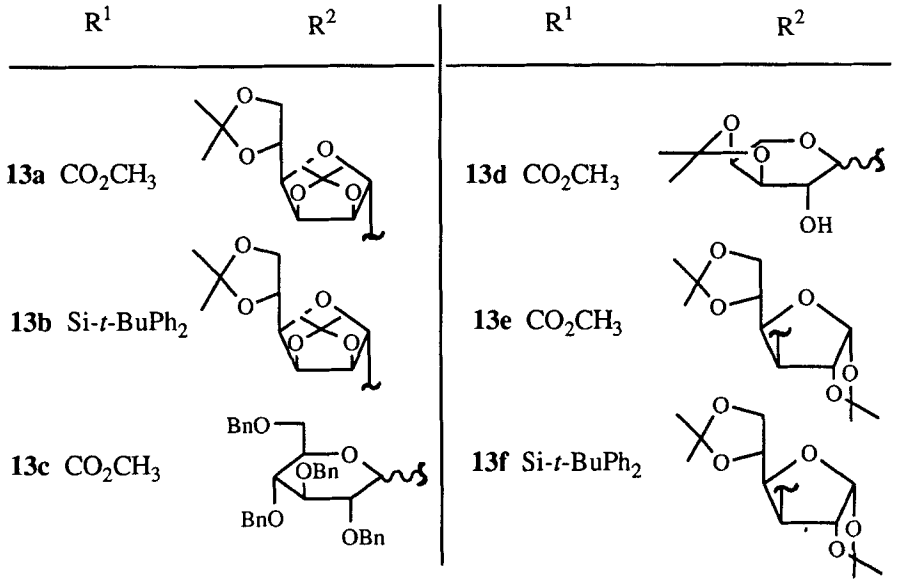


12



3 $R^1 = CO_2CH_3$
5 R^1 = Si-*t*-BuPh$_2$

13 a-f



Scheme 3

2,3;5,6-Di-*O*-isopropylidene-D-mannofuranose (**8**) reacted with unsaturated carbohydrates **3** and **5** to give stereo- and regiospecifically the disaccharides **13a** and **13b** in 43 % and 85 % yields respectively (Scheme 3). The α anomeric configuration of the furanose moiety was readily derived from the ^{1}H NMR data and particularly $J_{1',2'} \approx 0$ Hz according to published assignments.[9b,c] The vicinal coupling constant $J_{4,5} = 9.5$ Hz for H-4 and H-5 of the six membered ethyl enoside moiety indicated an anti relationship and proved the *erythro* configuration. The observed overall retention of configuration at C-4 is in agreement with the stereochemistry observed in the attack of π-allylic systems by oxygen nucleophiles.[11] The regioselectivity is also in agreement with the results of Baer concerning the *N*- and *C*-alkylation of such unsaturated carbohydrates catalysed by palladium complexes.[12]

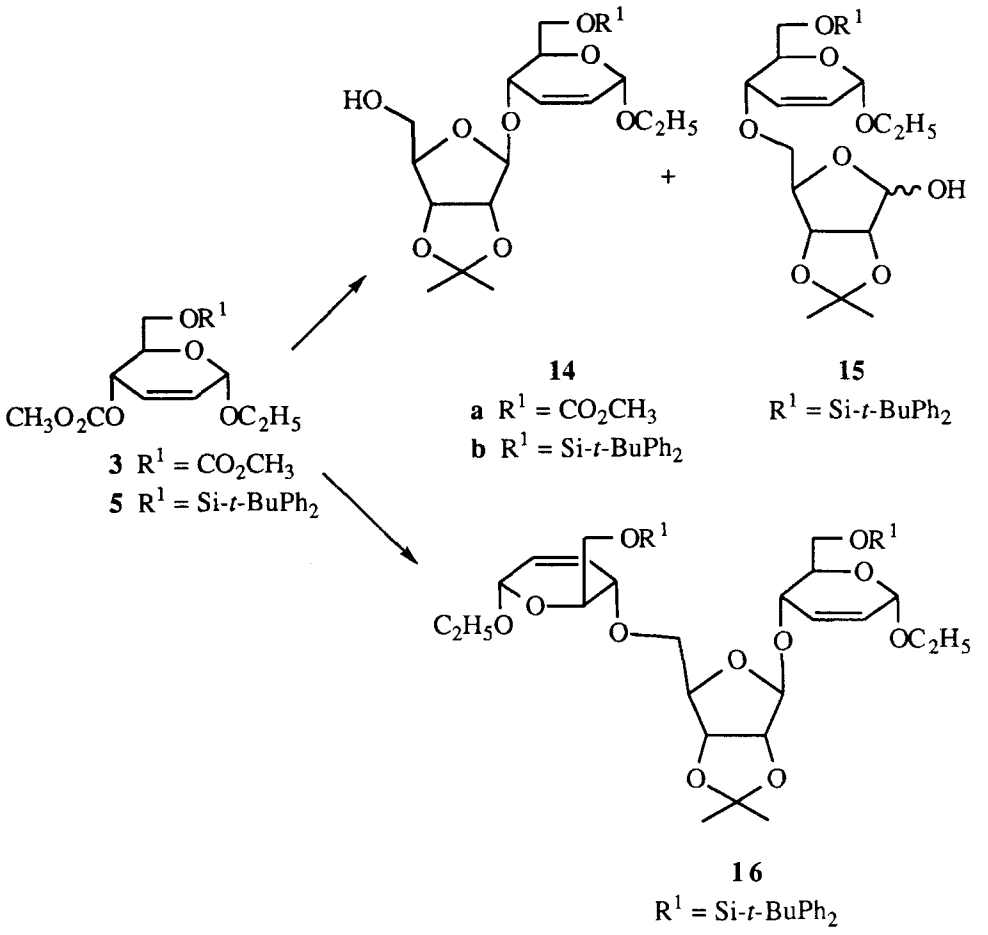
The reaction of the unsaturated carbohydrate **3** with 2,3,4,6-tetra-*O*-benzyl-D-glucopyranose (**9**) under the same conditions gave the disaccharide **13c** as an α/β mixture of 59/41 in 37 % yield. The α and β configuration of the glucopyranose moiety was derived from the ^{1}H NMR data. We observed for H-1' a doublet at δ 4.95 ppm with a coupling constant $J_{1',2'}$ = 3.5 Hz and a doublet at δ 4.79 ppm with a coupling constant $J_{1',2'}$ = 9.6 Hz characteristic for an α and β configuration, respectively. This assignment was confirmed from ^{13}C NMR data; due to the γ-gauche effect,[13] the signal of C-5' corresponding to the α anomer (δ 79.67 ppm) is at higher field than the signal of the β anomer (δ 82.25 ppm), and these values are in agreement with the literature data.[14] The overall retention of configuration at C-4 was also observed from the ^{1}H NMR data; the coupling constant $J_{4,5}$ = 9.8 and 9.5 Hz for the α and β anomers respectively are characteristic for a *trans* diaxial relation between H-4 and H-5.

It is to be noted that Pfeffer and coworkers[15] demonstrated by ^{13}C NMR investigations that 2,3,4,6-tetra-*O*-benzyl-D-glucopyranose (**9**) exists in tetrahydrofuran solution at 60 °C in an α/β = 70/30 anomeric ratio. So, in the *O*-alkylation reaction, the β-anomer formation could be attributed to the higher nucleophilicity of the generated β-1-alkoxide compared to the corresponding α-1-alkoxide combined with the rate of anomerization.

Changing the ligand dppb to tri(*o*-tolyl)phosphine, having a large cone angle of 194 °,[16] reversed the selectivity at the anomeric center; a mixture of **13c** α and **13c** β was obtained in 23 % yield and a 44/56 ratio.

This reaction was not limited to 1-hydroxy carbohydrates. For example 1,2;5,6-di-*O*-isopropylidene-α-D-glucofuranose (**10**) reacted with the α-D-*erythro* enosides **3** and **5** under the standard conditions to give the corresponding disaccharidic ethers **13f** and **13e** in 30 % and 58 % yield, respectively. It is to be noted again that the silyl protected carbohydrate **5** gave higher yield than the methoxycarbonyl protected carbohydrate **3** in this reaction. As expected, the two compounds **13f** and **13e** showed a coupling constant $J_{4,5}$ = 9.3 Hz characteristic for the *erythro* configuration and consequently of a net retention of configuration in the formation of the carbon-oxygen bond at C-4.

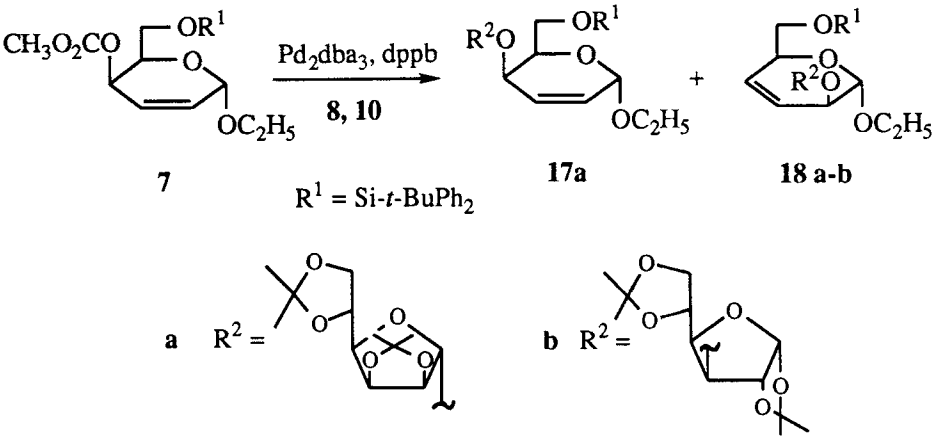
We then used as the nucleophile 3,4-*O*-isopropylidene-L-arabinose (**11**), possessing two free hydroxyl functions at C-1 and C-2. By reaction of compound **11** with the unsaturated carbohydrate **3**, we only observed the formation of the disaccharide **13d** resulting from the attack of the anomeric hydroxyl on the π-allyl system in 40 % chemical yield and as a mixture of α and β anomers in a 30/70 ratio. The α/β stereochemistry was based on the ^{1}H and ^{13}C NMR data. We observed for the α-anomer a doublet for H-1' at δ 4.26 ppm ($J_{1',2'}$ = 7.3 Hz) and for the β-anomer a doublet at δ 4.99 ppm ($J_{1',2'}$ = 3.6 Hz) in agreement with the literature data.[17] The chemical shifts for C-1' and C-5' are also at



Scheme 4

higher field for the α-anomer (δ = 103.62 and 64.10 ppm) compared to the β-anomer (δ = 94.93 and 61.04 ppm).

The reaction of carbohydrates **3** and **5** with 2,3-*O*-isopropylidene-D-ribofuranose (**12**) is more complex. Under the standard conditions of alkylation, the methoxycarbonyl protected carbohydrate **3** gave a single product **14a** (Scheme 4) as a single anomer in 30 % yield which could be increased to 70 % if an excess of **12** was used ([**3**]/[**12**] = 1/2 instead of 2/1). The β configuration of the furanose moiety was derived from the coupling constant $J_{1',2'} \approx 0$ Hz, characteristic for the β configuration according to published assignments,[18] and the *erythro* configuration was confirmed by the coupling constant $J_{4,5}$ = 9.5 Hz.

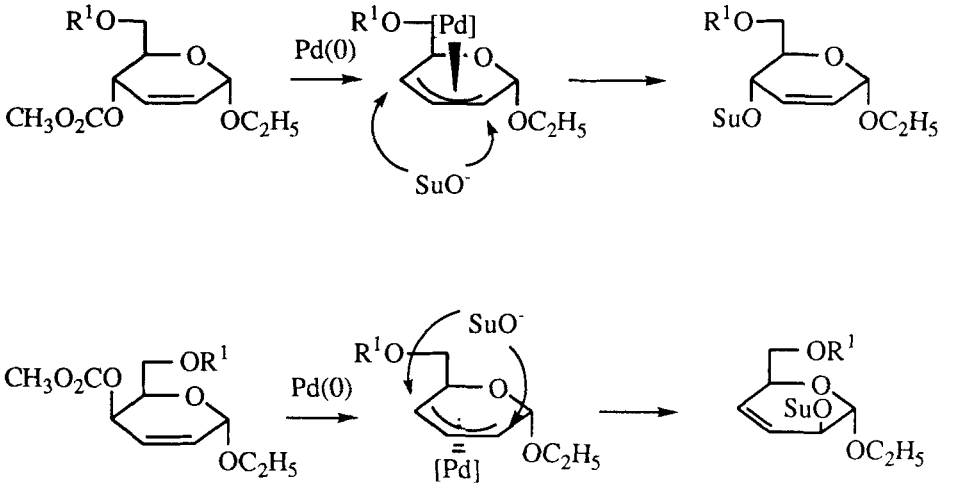


Scheme 5

When the silyl protected carbohydrate **5** was used as the π-allyl precursor, the expected disaccharide **14b** was obtained in 64 % yield together with the disaccharidic ether **15** (16 % yield). If the ^{1}H NMR characteristics of compound **14b** are close to those of compound **14a** ($J_{1',2'} \approx 0$ Hz, $J_{4,5} = 9.3$ Hz), the ^{1}H NMR spectrum of ether **15** indicated a mixture of α/β anomers in a 30/70 ratio; we observed for the anomeric proton H-1' a singlet at δ 5.27 ppm for the α anomer and a doublet at δ 5.19 ppm ($J_{1',2'} = 3.9$ Hz) for the β anomer.[18]

This result prompted us to perform the reaction of **12** with a large excess of **5**. When 3 equivalents of **5** were used, the trisaccharide **16** was obtained in 30 % yield after column chromatography. From the ^{1}H NMR data, the signals of H-4 appeared as two broad doublets at δ 3.97 and 4.22 ppm ($J_{4,5} = 9.3$ Hz) characteristic for an *erythro* configuration for the two unsaturated carbohydrate moieties. The H-1' signal appeared as a singlet at δ 5.20 ppm and confirmed the β configuration at the anomeric center of the ribofuranose moiety.

We then turned our attention to the coupling reaction between the α-D-*threo* enoside **7** and various hydroxycarbohydrates (Scheme 5). With mannofuranose derivative **8**, a mixture of the 4-*O*-alkylated-2,3-unsaturated carbohydrate **17a** and its 2-*O*-alkylated-3,4-unsaturated isomer **18a** was obtained in 21% and 61% yields, respectively. Compound **17a** shows for the unsaturated moiety ^{1}H and ^{13}C NMR data very close to the *threo* derivative **7** and consistent with the assignment of the 2,3-unsaturation and the *threo* configuration. For compound **18a**, we observed a noticeable downfield shift for C-1 (δ =



$R^1 = CO_2CH_3$ or Si-*t*-$BuPh_2$
Su-OH = carbohydrate

Scheme 6

98.24 ppm) characteristic for 3,4-unsaturation.[12] The very weak coupling $J_{1,2} \approx 0$ Hz observed is also characteristic of 3-enopyranosides having a α-D-*threo* configuration.

Reaction of the di-*O*-isopropylidene glucofuranose **10** with α-D-*threo* enoside **7** gave a unique disaccharide **18b** in 76% yield. The assignment of the structure of this compound was again based on ^1H and ^{13}C NMR data. The ^{13}C NMR spectrum of the unsaturated moiety of **18b** is very close to that of **18a** and particularly the chemical shift of C-1 at δ 98.19ppm. The singlet observed at δ 4.91 ppm for H-1 is characteristic of a 3,4-α-D-*threo*-hex-3-enopyranoside structure.

This difference in regioselectivity could be rationalized according to Scheme 6. Starting from the α-D-*erythro* or α-D-*threo* enopyranoside, the first step is the formation of the π-allyl system by oxidative addition to palladium(0), which occurs with inversion of configuration. It was recently shown that the attack of the oxygen nucleophile occurs *trans* to the palladium.[11] In the case of the π-allyl palladium complex obtained from the *erythro* compound, the attack of the nucleophile occurs only at C-4, the C-2 position being crowded by the aglycon. In contrast, for the π-allyl palladium complex obtained from the *threo* compound, the position at C-2 is now completely free and *O*-alkylation could occur at this position, although the C-4 position is crowded by the substituent on C-6. Such

difference in regioselectivity was previously noticed by Hanna and Baer in the case of *C*- and *N*-alkylation.[12]

CONCLUSION

In this paper, we have shown that unsaturated disaccharides could be obtained in quite good yields starting from α-*erythro* enosides **3** and **5** and various 1-hy-droxy carbohydrates under neutral conditions using palladium(0) as the catalyst. The reaction is regio- and stereoselective according to the unsaturated carbohydrate, and the α/β ratio of anomers depends of the carbohydrate used as the nucleophile. In the case of α-*threo* enoside **7** the reaction is only stereospecific, alkylation occuring at C-2 and C-4. The extension of this very mild methodology of glycosylation to the synthesis of other unsaturated disaccharides as well as their transformations into common and less common carbohydrates are currently under investigation and will be published elsewhere.

EXPERIMENTAL

General methods. All reactions were monitored by thin-layer chromatography carried out on 0.25 mm silica gel plates (60F-254, Merck). Column chromatography was performed on silica gel 60 (230-480 mesh ASTM, Macherey-Nagel). NMR spectra were obtained in $CDCl_3$ and chemical shifts are given in ppm on the δ scale from internal tetramethylsilane; they were recorded on Bruker AC 200, Bruker AM 300 and Varian Unity 500 apparatus (H' or C' refer to the saturated moiety of the disaccharide). Optical rotations were measured on a Perkin-Elmer 241 polarimeter. THF was distilled from sodium/ benzophenone and kept under a nitrogen atmosphere. Reactions involving palladium complexes were carried out in a Schlenk tube under a nitrogen atmosphere. $Pd_2(dba)_3$, 2,3;5,6-di-*O*-isopropylidene-D-mannofuranose (**8**), 2,3,4,6-tetra-*O*-benzyl-D-glucopyranose (**9**) and 1,2;5,6-di-*O*-isopropylidene-α-D-glucofuranose (**10**) are from commercial source. Ethyl 4,6-di-*O*-acetyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (**1**),[3] 2,3-*O*-isopropylidene-D-ribofuranose (**12**),[19] and 3,4-*O*-isopropylidene-L-arabino-pyranose (**11**)[20] were prepared according to literature procedures.

Ethyl 4,6-Di-*O*-methoxycarbonyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (3). To a 0.1 M solution of sodium methanolate in methanol (20 mL) was added the diacetate **1** (2.0 g, 6.5 mmol). After being stirred at 25 °C for 2 h, the solvent was evaporated and the crude diol obtained used without further purification. To a solution of diol **2** (2.0 g, 11.5 mmol) in anhydrous dichloromethane (20 mL) at 0 °C was added 5 equiv of pyridine (4.5 g, 57.4 mmol) and 0.2 g of DMAP followed methyl

chloroformate (5.4 g, 57.4 mmol). After completion of the reaction (5 h), the solution was diluted with water (10 mL) and extracted with dichloromethane (3x30 mL). Evaporation of the solvent followed by column chromatography (eluent hexane/ethyl acetate 1:1 v/v) gave compound **3** (2.7 g, 82 %): oil; R_f 0.7; $[\alpha]_D^{20}$ +102.3 (*c* 1, chloroform); ^1H NMR (200 MHz) δ 1.24 (t, J = 7.1 Hz, 3H, CH_2CH_3), 3.56 (dq, J = 9.7 and 7.1 Hz, 1H, CH_2CH_3), 3.70 - 3,90 (m, 7H, CH_2CH_3, 2 x OCH_3), 4.15 (dt, J = 9.5 and 3.9 Hz, 1H, H-5), 4.33 (d, J = 3.9 Hz, 2H, H-6), 5.04 (bs, 1H, H-1), 5.18 (bd, J = 9.5 Hz, 1H, H-4), 5.85 (ddd, J = 10.3, 2.4 and 1.7 Hz, 1H, H-2), 5.96 (bd, J = 10.3 Hz, 1H, H-3); ^{13}C NMR (50.3 MHz) δ 15.27 (CH_3CH_2), 54.90 (OCH_3), 55.12 (OCH_3), 64.33 (CH_3CH_2), 66.37 (C-6), 66.54 and 68.95 (C-4, C-5), 94.09 (C-1), 128.35 and 128.47 (C-2, C-3), 170.26, 170.73 (CO).

Anal. Calcd for $C_{12}H_{18}O_8$ (290.27): C, 49.66; H, 6.25. Found: C, 49.71; H, 6.15.

Ethyl 6-*O*-*tert*-Butyldiphenylsilyl-4-*O*-methoxycarbonyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (5). To a solution of the diol **2** (1.5 g, 0.86 mmol) in dichloromethane (30 mL) was slowly added triethylamine (1.6 mL, 11.2 mmol) and and *tert*-butyldiphenylsilyl chloride (2.9 mL, 11.2 mmol). After being stirred at room temperature for 24 h, the solution was diluted with water (50 mL) and extracted with dichloromethane (3x50 mL). Evaporation of the solvent followed by column chromatography (eluent hexane/ethyl acetate 1:1 v/v) gave compound **4** (2.6 g, 72 %) as an oil.To a dichloromethane solution (20 mL) containing this alcohol **4** (1.0 g, 2.4 mmol), pyridine (0.4 g, 4.8 mmol) and DMAP (0.1 g) maintained at 0 °C was added methyl chloroformate (454 mg, 4.8 mmol). After being stirred at room temperature for 24 h, the solution was diluted with water (10 mL) and extracted with dichloromethane (3x30 mL). Evaporation of the solvent followed by column chromatography (eluent hexane/ethyl acetate 4:1 v/v) gave the carbonate **5** (1.06 g, 94 %): oil; R_f 0.57; $[\alpha]_D^{20}$ +44.5 (*c* 1, chloroform); ^1H NMR (200 MHz) δ 1.05 (s, 9H, CMe_3), 1.22 (t, J = 7.1 Hz, 3H, CH_2CH_3), 3.55 (dq, J = 9.6 and 7.1 Hz, 1H, CH_2CH_3), 3.74 (s, 3H, OCH_3), 3.82 (d, J = 3.8 Hz, 2H, H-6), 3.88 (dq, J = 9.6 and 7.1 Hz, 1H, CH_2CH_3), 4.03 (dt, J = 9.5 and 3.8 Hz, 1H, H-5), 5.05 (bs, 1H, H-1), 5.23 (dd, J = 9.5 and 2.5 Hz, 1H, H-4), 5.85 (ddd, J = 10.4, 2.5 and 1.8 Hz, 1H, H-2), 5.97 (bd, J = 10.4 Hz, 1H, H-3), 7.33-7.45 (m, 6H, C_6H_5), 7.67-7.73 (m, 4H, C_6H_5); ^{13}C NMR (50.3 MHz) δ 15.24 (CH_3CH_2), 19.24 (CMe_3), 26.71 (CMe_3), 54.90 (OCH_3), 63.35 and 63.95 (C-6, CH_2CH_3), 69.23 and 69.29 (C-4, C-5), 93.91 (C-1), 127.63, 128.38, 128.88, 129.61, 133.33, 133.47, 135.60 and 135.71 (C-2, C-3, C_6H_5), 155.15 (CO).

Anal. Calcd for $C_{26}H_{34}O_6Si$ (470.64): C, 66.38; H, 7.25. Found: C, 66.41; H, 7.24.

Ethyl 6-*O*-*tert*-Butyldiphenylsilyl-4-*O*-methoxycarbonyl-2,3-dideoxy-α-D-*threo*-hex-2-enopyranoside (7). To a solution of compound **4** (1.0 g, 2.4 mmol) in toluene (25 mL) was added triphenylphosphine (1.27 g, 4.8 mmol) and chloroacetic acid (0.45 g, 4.8 mmol). After being stirred at 25 °C for 15 min, diethyl azodicarboxylate (0.84 g, 4.8 mmol) was added and the solution was stirred for 24 h. The solution was filtered and then washed with hexane and concentrated. The resulting oil was dissolved in methanol (25 mL) and treated with a catalytic amount of sodium methanolate. After 12 h, the solution was concentrated, the oil was dissolved in dichloromethane (30 mL) and the solution washed with a 0.1 aqueous solution of ammonium chloride. Evaporation of the solvent followed by column chromatography of the residue (eluent hexane/ethyl acetate 2:1 v/v) gave the *threo* derivative **6** (290 mg, 29 %) as an oil. Following the procedure described for **5**, the carbonate **7** was obtained (1.1 g, 96 %): oil; R_f 0.48 (hexane/ethyl acetate 4:1 v/v); $[\alpha]_D^{20}$ -100.3 (*c* 0.9, chloroform); ^{1}H NMR (200 MHz) δ 1.04 (s, 9H, CMe_3), 1.19 (t, J = 7.1 Hz, 3H, CH_2CH_3), 3.50 (dq, J = 9.6 and 7.1 Hz, 1H, CH_2CH_3), 3.74 (s, 3H, OCH_3), 3.74 - 3.82 (m, 3H, CH_2CH_3 and H-6), 4.27 (ddd, J = 6.8, 6.8 and 2.4 Hz, 1H, H-5), 4.95 (dd, J = 5.3 and 2.4 Hz, 1H, H-4), 5.03 (d, J = 2.8 Hz, 1H, H-1), 6.04 (dd, J = 10.0 and 2.8 Hz, 1H, H-2), 6.22 (dd, J = 10.0 and 5.3 Hz, 1H, H-3), 7.34-7.47 (m, 6H, C_6H_5), 7.64 -7.71 (m, 4H, C_6H_5); ^{13}C NMR (50.3 MHz) δ 15.23 (CH_3CH_2), 19.13 (CMe_3), 26.65 (CMe_3), 54.77 (OCH_3), 62.36 and 63.73 (C-6, CH_2CH_3), 69.33 and 69.04 (C-4, C-5), 93.61 (C-1), 124.94, 127.72, 129.72, 129.73, 131.39, 133.25, 133.29, 135.92 and 135.93 (C-2, C-3, C_6H_5), 155.35 (CO).

Anal. Calcd for $C_{26}H_{34}O_6Si$ (470.64): C, 66.38; H, 7.25. Found: C, 66.19; H, 7.20.

General Procedure for Palladium-Catalysed Synthesis of Disaccharides. The catalytic system was prepared by stirring for 1 h in a Schlenk tube under argon $Pd_2(dba)_3$ (22.9 mg, 0.025 mmol) and dppb (42.6 mg, 0.1 mmol) in tetrahydrofuran (5 mL). This solution was added under argon to a Schlenk tube containing the unsaturated carbohydrate (1 mmol) and the 1-hydroxy sugar (2 mmol) in tetrahydrofuran (5 mL). After stirring for 24 h at the desired temperature, the solvent was evaporated and the residue was chromatographied on silica gel to give the disaccharide.

Ethyl 4-*O*-(2,3;5,6-Di-*O*-isopropylidene-α-D-mannofuranosyl)-6-*O*-methoxycarbonyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (13a). Yield 43 %; oil; R_f 0.44 (dichloromethane/hexane/diethyl ether 4:1:3 v/v); $[\alpha]_D^{20}$ +104.8 (*c* 1, chloroform); ^{1}H NMR (500 MHz) δ 1.23 (t, J = 7.1 Hz, 3H, CH_2CH_3), 1.33 (s, 3H, CH_3), 1.37 (s, 3H, CH_3), 1.44 (s, 3H, CH_3), 1.47 (s, 3H, CH_3), 3.48 (dq, J = 9.5 and 7.1 Hz, 1H, CH_2CH_3), 3.73 (s, 3H, OCH_3), 3.75 (dq, J = 9.5 and 7.1 Hz, 1H,

CH_2CH_3), 3.83 (dd, J = 8.0 and 4.0 Hz, 1H, H-4'), 3.88 (ddd, J = 9.5, 5.0 and 2.3 Hz, 1H, H-5), 3.94 (dd, J = 9.0 and 4.5 Hz, 1H, H-6'), 4.02 (dd, J = 9.0 and 6.5 Hz, 1H, H-6'), 4.18 (dd, J = 12.0 and 5.0 Hz, 1H, H-6), 4.22 (ddd, J = 9.5, 3.0 and 1.5 Hz, 1H, H-4), 4.30 (dd, J = 12.0 and 2.3 Hz, 1H, H-6), 4.31 (ddd, 1H, J = 8.0, 6.5 and 4.5 Hz, H-5'), 4.51 (d, J = 5.5 Hz, 1H, H-2'), 4.73 (dd, J = 5.5 and 4.0 Hz, 1H, H-3'), 4.93 (dd, J = 2.0 and 1.5 Hz, 1H, H-1), 5.12 (s, 1H, H-1'), 5.74 (ddd, J = 10.5, 3.0 and 2.0 Hz, 1H, H-2), 5.97 (d, 1H, J = 10.5 Hz, H-3); ^{13}C NMR (50.3 MHz) δ 15.29 (CH_2CH_3), 24.58 (Me), 25.32 (Me), 25.92 (Me) , 26.83 (Me), 54.87 (OCH_3), 64.17 (CH_2CH_3), 69.53 and 67.46 (C-4, C-5), 66.67 and 66.88 (C-6, C-6'), 73.00 (C-5'), 79.56 and 81.12 (C-2', C-3'), 85.33 (C-4'), 94.21 (C-1), 103.81 (C-1'), 109.28 (CMe_2), 112.81 (CMe_2), 127.38 and 128.48 (C-2, C-3), 155.68 (CO_2).

Anal. Calcd for $C_{22}H_{34}O_{11}$ (474.51): C, 55.69; H, 7.17. Found: C, 55.27; H, 7.14.

Ethyl 6-*O*-*tert*-Butyldiphenylsilyl-4-*O*-(2,3;5,6-di-*O*-isopropylidene-α-D-mannofuranosyl)-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (13b). Yield 85 %; oil; R_f 0.64 (dichloromethane/hexane/diethyl ether 4:1:3 v/v); $[\alpha]_D^{20}$ +71.4 (*c* 0.9, chloroform); ^1H NMR (300 MHz) δ 1.06 (s, 9H, CMe_3), 1.18 (s, 3H, CH_3), 1.24 (t, J = 7.1 Hz, 3H, CH_2CH_3), 1.29 (s, 3H, CH_3), 1.30 (s, 3H, CH_3), 1.42 (s, 3H, CH_3), 3.51 (dd, J = 7.1 and 3.6 Hz, 1H, H-4'), 3.54 (dq, J = 9.6 and 7.1 Hz, 1H, CH_2CH_3), 3.70-3.80 (m, 3H, H-5, H-6), 3.94 (dq, J = 9.6 and 7.1 Hz, 1H, CH_2CH_3), 3.90-4.00 (m, 2H, H-6'), 4.01 (ddd, J = 9.5, 1.8 and 1.8 Hz, 1H, H-4), 4.22 (ddd, J = 7.1, 6.3 and 6.3 Hz, 1H, H-5'), 4.42 (d, J = 5.9 Hz, 1H, H-2'), 4.51 (dd, J = 5.9 and 3.6 Hz, 1H, H-3'), 4.99 (d, J = 2.6 Hz, 1H, H-1), 5.12 (s, 1H, H-1'), 5.83 (ddd, J = 10.3, 2.6 and 1.8 Hz, 1H, H-2), 6.00 (bd, J = 10.3 Hz, 1H, H-3), 7.32-7.42 (m, 6H, C_6H_5), 7.67-7.73 (m, 4H, C_6H_5); ^{13}C NMR (50.3 MHz) δ 15.24 (CH_2CH_3), 19.22 (CMe_3), 24.60 (CMe_2), 25.25 (CMe_2), 25.89 (CMe_2), 26.60 (CMe_2), 26.78 (CMe_3), 63.74 (C-6), 64.15 (CH_2CH_3), 66.87 (C-6'), 66.87 and 70.94 (C-4, C-5), 72.91 (C-5'), 79.51 and 80.93 (C-2', C-3'), 85.33 (C-4'), 93.65 (C-1), 103.49 (C-1'), 109.05 and 112.66 (CMe_2), 127.51, 127.62, 127.67, 128.53, 129.53, 133.52, 133.70, 135.63 and 135.87 (C-2, C-3, C_6H_5).

Anal. Calcd for $C_{36}H_{50}O_9Si$ (654.88): C, 66.06; H, 7.65. Found: C, 65.82; H, 7.78.

Ethyl 4-*O*-(2,3,4,6-Tetra-*O*-benzyl-D-glucopyranosyl)-6-*O*-methoxycarbonyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (13c). Yield 37 % (α/β = 59/41) with dppb; 23 % (α/β = 44/56) with (o-$CH_3C_6H_4)_3P$; oil; R_f 0.54 (dichloromethane/hexane/diethyl ether 4:3:1 v/v); ^1H NMR (500 MHz) α anomer (in the α/β mixture) δ 1.23 (t, J = 7.1 Hz, 3H, CH_2CH_3), 3.41-3.84 (m, 6H, CH_2CH_3, H-2', H-

4', H-5', H-6'), 3.71 (s, 3H, OCH_3), 3.91 (dd, J = 9.0 and 9.0 Hz, 1H, H-3'), 4.04-4.12 (m, 1H, H-5), 4.24 (bd, J = 9.8 Hz, 1H, H-4), 4.31 (dd, J = 11.6 and 5.1 Hz, 1H, H-6), 4.36 (dd, J = 11.6 and 4.6 Hz, 1H, H-6), 4.40 - 4.93 (m, 8H, OCH_2Ph), 4.95 (d, J = 3.5, 1H, H-1'), 4.99 (bs, 1H, H-1), 5.78 (ddd, J = 10.3, 2.2 and 2.2 Hz, 1H, H-2), 5.94 (bd, J = 10.3 Hz, 1H, H-3), 7.00-7.40 (m, 20H, C_6H_5); β anomer (in the α/β mixture) δ 1.25 (t, J = 7.0 Hz, 3H, CH_2CH_3), 3.41-3.84 (m, 7H, CH_2CH_3, H-2', H-3', H-4', H-5', H-6'), 3.74 (s, 3H, OCH_3), 4.04-4.12 (m, 1H, H-5), 4.28 (bd, J = 9.5 Hz, 1H, H-4), 4.31 (dd, J = 11.6 and 5.1 Hz, 1H, H-6), 4.36 (dd, J = 11.6 and 4.6 Hz, 1H, H-6), 4.40 - 4.93 (m, 8H, OCH_2Ph), 4.79 (d, J = 9.6 Hz, 1H, H-1'), 4.99 (bs, 1H, H-1), 5.77 (ddd, J = 10.1, 2.4 and 2.4 Hz, 1H, H-2), 6.15 (bd, J = 10.1 Hz, 1H, H-3), 7.00-7.40 (m, 20H, C_6H_5); ^{13}C NMR (50.3 MHz) α anomer (in the α/β mixture) δ 15.30 (CH_2CH_3), 54.70 (OCH_3), 64.02 (CH_2CH_3), 66.85 (C-6), 67.41 (C-4), 68.08 (C-6'), 68.71 (C-5), 71.23 (C-4'), 73.39-75.68 (CH_2C_6H5), 77.45 (C-2'), 79.67 (C-5'), 81.90 (C-4'), 94.24 (C-1), 95.66 (C-1'), 126.66-138.72 (C-2, C-3 and C_6H_5), 155.61 (CO_2); β anomer (in the α/β mixture) δ 15.30 (CH_2CH_3), 54.78 (OCH_3), 64.02 (CH_2CH_3), 64.12 (CH_2CH_3), 66.64 (C-6), 67.73 (C-2), 68.85 (C-6'), 71.23 (C-4'), 72.17 (C-5), 73.39-75.68 (CH_2C_6H5), 77.68 (C-2'), 82.25 (C-5'), 84.68 (C-3'), 94.13 (C-1), 104.19 (C-1'), 126.66-138.72 (C-2, C-3 and C_6H_5), 155.55 (CO_2).

Anal. Calcd for $C_{44}H_{50}O_{11}$ (754.88): C, 70.03; H, 6.63. Found: C, 69.92; H, 6.70.

Ethyl 4-*O*-(3,4-*O*-Isopropylidene-L-arabinopyranosyl)-6-*O*-methoxycarbonyl-3,4-dideoxy-α-D-*erythro*-hex-2-enopyranoside (13d). Yield 40 % (α/β 30/70); oil; R_f 0.27 (petroleum ether/dichloromethane/diethyl ether 6:1:3 v/v); ^1H NMR (500 MHz) α anomer (in the α/β mixture) δ 1.21 (t, J = 7.1 Hz, 3H, CH_2CH_3), 1.34 (s, 3H, CH_3), 1.51 (s, 3H, CH_3), 2.09 (bs, 1H, OH), 3.54 (dq, 1 H, J = 9.6 et 7.1 Hz, 1H, CH_2CH_3), 3.77 (s, 3H, OCH_3), 3.78-4.44 (m, 10H, H-4, H-5, H-6, H-2', H-3', H-4', H-5', CH_2CH_3), 4.26 (d, J = 7.3 Hz, H-1'), 4.98 (s, 1H, H-1), 5.68 (ddd, J = 10.3, 2.1 et 2.1 Hz, 1H, H-2), 6.07 (d, J = 10.3 Hz, 1H, H-3) ; β anomer (in the α/β mixture) δ 1.21 (t, J = 7.1 Hz, 3H, CH_2CH_3), 1.34 (s, 3H, CH_3), 1.49 (s, 3H, CH_3), 2.09 (bs, 1H, OH), 3.54 (dq, 1 H, J = 9.6 et 7.1 Hz, 1H, CH_2CH_3), 3.61 (dd, J = 7.5 et 7.5 Hz, 1H, H-5'), 3.77 (s, 3H, OCH_3), 3.78-4.44 (m, 90H, H-4, H-5, H-6, H-2', H-3', H-4', H-5', CH_2CH_3), 4.98 (s, 1H, H-1), 4.99 (d, J = 3.6 Hz, 1H, H-1'), 5.81 (ddd, J = 10.3, 2.1 et 2.1 Hz, 1H, H-2), 5.99 (d, J = 10.3 Hz, 1H, H-3); ^{13}C NMR (50.3 MHz): α anomer (in the α/β mixture) δ 15.28 (CH_3CH_2), 25.94 (CH_3), 27.91 (CH_3), 55.00 (OCH_3), 62.97 (C-6), 64.13 (C-5'), 64.21 (CH_2CH_3), 69.91, 72.26, 72.92, 73.54 and 78.08 (C-4, C-5, C-2', C-3', C-4'), 94.16 (C-1), 103.62 (C-1'), 110.18 (CMe_2), 126.84 and 131.82 (C-2, C-3), 155.86 (CO_2); β anomer (in the α/β

mixture) 15.28 (CH_3CH_2), 25.55 (CH_3), 27.52 (CH_3), 54.92 (OCH_3), 61.04 (C-5'), 64.21 (CH_2CH_3), 67.06 (C-6), 67.74, 67.95, 68.82, 72.39 and 74.93 (C-4, C-5, C-2', C-3', C-4'), 94.07 (C-1), 94.93 (C-1'), 109.31 (CMe_2), 127.68 and 128.89 (C-2, C-3), 155.81 (CO_2).

Anal. Calcd for $C_{18}H_{28}O_{10}$ (404.42): C, 53.46; H, 6.98. Found: C, 53.73; H, 7.25.

Ethyl 4-*O*-(1,2;5,6-Di-*O*-isopropylidene-α-D-glucofuranos-3-yl)-6-*O*-methoxycarbonyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (13e). Yield 58 %; oil; R_f 0.28 (dichloromethane/hexane/diethyl ether 4:1:3 v/v); $[\alpha]_D^{20}$ +37.6 (*c* 1.1, chloroform); ^1H NMR (300 MHz) δ 1.26 (t, J = 7.1 Hz, 3H, CH_2CH_3), 1.31 (s, 3H, CH_3), 1.34 (s, 3H, CH_3), 1.41 (s, 3H, CH_3), 1.49 (s, 3H, CH_3), 3.53 (dq, J = 9.6 and 7.1 Hz, 1H, CH_2CH_3), 3.78 (s, 3H, OCH_3), 3.82 (dq, J = 9.6 and 7.1 Hz, 1H, CH_2CH_3), 3.97 (dd, J = 8.7 and 5.3 Hz, 1H, H-6'), 3.96 - 4.00 (m, 2H, H-5, H-3'), 4.03 (dd, J = 7.9 and 3.0 Hz, 1H, H-4'), 4.11 (dd, J = 8.7 and 6.2 Hz, 1H, H-6'), 4.15 (bd, J = 9.3 Hz, 1H, H-4), 4.24 (ddd, J = 7.9, 6.2 and 5.3 Hz, 1H, H-5'), 4.44 (dd, J = 11.5 and 5.3 Hz, 1H, H-6), 4.50 (dd, J = 11.5 and 2.0 Hz, 1H, H-6), 4.52 (d, J = 3.7 Hz, 1H, H-2'), 4.99 (bd, J = 2.0 Hz, 1H, H-1), 5.81 (ddd, J = 10.2, 2.5 and 2.0 Hz, 1H, H-2), 5.86 (d, J = 3.7 Hz, 1H, H-1'), 6.03 (d, J = 10.2 Hz, 1H, H-3); ^{13}C NMR (50.3 MHz) δ 15.27 (CH_2CH_3), 25.06 (CH_3), 26.24 (CH_3), 26.85 (CH_3, double intensity), 54.74 (OCH_3), 64.16 (CH_2CH_3), 66.87 and 67.79 (C-6, C-6'), 68.02, 71.79 and 72.12 (C-4, C-5, C-5'), 81.45 and 82.07 (C-2', C-3'), 83.82 (C-4'), 94.00 (C-1), 105.32 (C-1'), 109.30 (CMe_2), 112.05 (CMe_2), 127.52 (C-2), 130.30 (C-3), 115.68 (CO_2).

Anal. Calcd for $C_{22}H_{34}O_{11}$ (474.51): C, 55.69; H, 7.17. Found: C, 55.68; H, 7.27.

Ethyl 4-*O*-(1,2;5,6-Di-*O*-isopropylidene-α-D-glucofuranos-3-yl)-6-*O*-*tert*-butyldiphenylsilyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (13f). Yield 58 %; oil; R_f 0.53 (dichloromethane/hexane/diethyl ether 4:1:3 v/v); $[\alpha]_D^{20}$ +23.4 (*c* 1, chloroform); ^1H NMR (500 MHz) δ 0.98 (s, 3H, CMe_2), 1.04 (s, 9H, CMe_3), 1.22 (t, J = 7.3 Hz, 3H, CH_2CH_3), 1.26 (s, 3H,CMe_2), 1.28 (s, 3H, CMe_2), 1.45 (s, 3H, CMe_2), 3.53 (dq, J = 9.7 and 7.3 Hz, 1H, CH_2CH_3), 3.84-4.09 (m, 5H, H-5, H-5', H-6', CH_2CH_3), 3.84 (d, J = 5.4, 2H, H-6), 3.96 (dd, J = 8.3 and 2.9 Hz, 1H, H-4'), 4.08 (d, J = 2.9 Hz, 1H, H-3'), 4.10 (bd, J = 9.3 Hz, 1H, H-4), 4.48 (d, J = 3.9 Hz, 1H, H-2'), 5.00 (bs, 1H, H-1), 5.81 (ddd, J = 10.2, 3.1 and 3.1 Hz, 1H, H-2), 5.82 (d, J = 3.9 Hz, 1H, H-1'), 6.02 (d, J = 10.2 Hz, 1H, H-3), 7.32-7.40 (m, 6H, C_6H_5), 7.69-7.73 (m, 4H, C_6H_5); ^{13}C NMR (50.3 MHz) δ 15.25 (CH_2CH_3), 19.31 (CMe_3), 24.97 (CH_3), 26.31 (CH_3), 26.78 (CH_3, CMe_3), 26.89 (CH_3), 63.64 and 63.73

(C-6, CH_2CH_3), 67.49 (C-6'), 71.17 and 71.35 (C-4, C-5), 72.18 (C-5'), 81.04 and 81.42 (C-3', C-4'), 84.04 (C-2'), 93.71 (C-1), 105.28 (C-1'), 108.93 (CMe_2), 111.10 (CMe_2), 127.56, 127.60, 129.56, 129.60, 130.71, 133.54, 133.71, 135.62 and 135.76 (C-2, C-3, C_6H_5).

Anal. Calcd for $C_{36}H_{50}O_9Si$ (654.88): C, 66.06; H, 7.65. Found: C, 66.17; H, 7.54.

Ethyl 4-*O*-(2,3-*O*-Isopropylidene-β-D-ribofuranosyl)-6-*O*-methoxycarbonyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (14a). Yield 54 % (70 % with two equivalents of the dicarbonate); oil; R_f 0.38 (dichloromethane/diethyl ether 4:1 v/v); $[\alpha]_D^{20}$ +16.8 (*c* 1, chloroform); ^1H NMR (500 MHz) δ 1.23 (dd, J = 7.2 and 7.1 Hz, 3H, CH_2CH_3), 1.32 (s, 3H, CH_3), 1.48 (s, 3H, CH_3), 2.93 (d, J = 10.0 Hz, 1H, OH), 3.55 (dq, J = 9.5 and 7.2 Hz, 1H, CH_2CH_3), 3.64 (ddd, J = 12.6, 10.0 and 3.4 Hz, 1H, H-5'), 3.74 (bd, J = 12.6 Hz, 1H, H-5'), 3.81 (s, 3H, OCH_3), 3.81 (dq, J = 9.5 and 7.1 Hz, 1H, CH_2CH_3), 4.01 (ddd, J = 9.5, 4.7 and 2.3 Hz, 1H, H-5), 4.25 (bd, J = 9.5 Hz, 1H, H-4), 4.34 (dd, J = 11.5 and 4.7 Hz, 1H, H-6), 4.41 (dd, J = 11.5 and 2.3 Hz, 1H, H-6), 4.42 (m, 1 H, H-4'), 4.62 (d, J = 5.9 Hz, 1H, H-2' or H-3'), 4.82 (d, J = 5.9 Hz, 1H, H-2' or H-3'), 4.99 (bs, 1 H, H-1), 5.22 (s, 1 H, H-1'), 5.81 (ddd, J = 10.2, 1.9 and 1.9 Hz, 1H, H-2), 6.14 (bd, J = 10.2 Hz, 1H, H-3); ^{13}C NMR (75 MHz) δ 15.26 (CH_3), 24.67 (CH_3), 26.38 (CH_3), 54.95 (OCH_3), 63.75, 66.49 and 64.28 (CH_2CH_3, C-5', C-6), 67.39 and 72.55 (C-4, C-5), 81.57, 86.33 and 88.65 (C-2', C-3', C-4'), 94.11 (C-1), 110.77 (C-1'), 112.29 (CMe_2), 127.95 and 130.35 (C-2, C-3), 155.71 (CO_2).

Anal. Calcd for $C_{18}H_{28}O_{10}$ (404.42): C, 53.46; H, 6.98. Found: C, 53.09; H, 6.96.

Ethyl 6-*O*-*tert*-Butyldiphenylsilyl-4-*O*-(2,3-*O*-isopropylidene-β-D-ribofuranosyl)-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (14b). Yield 63 % ; oil; R_f 0.45 (petroleum ether/ethyl acetate 2:1 v:v); $[\alpha]_D^{20}$ -12.1 (*c* 0.6, chloroform); ^1H NMR (500 MHz) δ 1.03 (s, 9H, CMe_3), 1.18 (t, J = 7.2 Hz, 3H, CH_2CH_3), 1.30 (s, 3 H, CH_3), 1.44 (s, 3 H, CH_3), 2.98 (dd, J = 10.8 and 2.4 Hz, 1H, OH), 3.51 (dq, J = 9.8 and 7.2 Hz, 1H, CH_2CH_3), 3.60 (ddd, J = 12.7, 10.8 and 3.4 Hz, 1H, H-5'), 3.70 (ddd, J = 12.7, 2.4 and 2.4 Hz, 1H, H-5'), 3.76 - 3,82 (m, 3H, CH_2CH_3, H-5, H-6), 3.87 (dd, J = 11.7 and 4.4 Hz, 1H, H-6), 4.41 (m, 1 H, H-4'), 4.43 (bd, J = 9.3 Hz, 1H, H-4), 4.49 (d, J = 5.9 Hz, 1H, H-2' or H-3'), 4.79 (d, J = 5.9 Hz, 1H, H-2' or H-3'), 5.00 (s, 1 H, H-1), 5.30 (s, 1 H, H-1'), 5.78 (ddd, J = 10.3, 2.9 and 2.0 Hz, 1H, H-2), 6.08 (d, J = 10.3 Hz, 1H, H-3), 7.35-7.42 (m, 6H, C_6H_5), 7.71-7.76 (m, 4H, C_6H_5); ^{13}C NMR (50.3 MHz) δ 15.26 (CH_2CH_3), 19.27 (CMe_3), 24.85 (CH_3), 26.42 (CH_3), 26.74 (CMe_3), 62.91, 63.82 and 63.89 (CH_2CH_3, C-5', C-6),

70.43 and 72.03 (C-4, C-5), 81.72, 86.27 and 88.54 (C-2', C-3', C-4'), 94.06 (C-1), 110.79 (C-1'), 112.14 (*C*Me$_2$), 127.59-133.45 (C$_6$H$_5$, C-2, C-3).

Anal. Calcd for $C_{32}H_{44}O_8Si$ (584.79): C, 65.73; H, 7.58. Found: C, 65.18; H, 7.98.

Ethyl 4-*O*-(2,3-*O*-Isopropylidene-D-ribofuranos-5-yl)-6-*O*-*tert*-butyl diphenylsilyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (15). Yield 16 % (α/β 30/70); oil; R*f* 0.52 (petroleum ether/ethyl acetate 2:1 v/v); $[\alpha]_D^{20}$ +42.0 (*c* 0.9, chloroform); ^{1}H NMR (500 MHz) α anomer (in the mixture of α and β anomers) δ 1.04 (s, 9 H, CMe$_3$), 1.21 (dd, J = 7.3 and 6.8 Hz, 3H, CH$_2$C*H*$_3$), 1.33 (s, 3H, CH$_3$), 1.46 (s, 3H, CH$_3$), 3.51 (dq, J = 9.8 and 6.8 Hz, 1H, C*H*$_2$CH$_3$), 3.60 (dd, J = 10.2 and 2.9 Hz, 1H, H-5'), 3.64 (dd, J = 10.2 and 3.4 Hz, 1H, H-5'), 3.80 (dq, J = 9.8 and 7.1 Hz, 1H, C*H*$_2$CH$_3$), 3.83-3.89 (m, 4H, H-5, H-6, OH), 3.96 (d, J = 8.8 Hz, 1H, H-4), 4.14 (bs, 1H, H-4'), 4.35 (dd, J = 6.3 and 3.9 Hz, 1H, H-2'), 4.58 (d, J = 6.3 Hz, 1H, H-3'), 5.00 (bs, 1H, H-1), 5.19 (dd, J = 11.2 and 3.9 Hz, 1H, H-1'), 5.80 (bd, J = 10.2 Hz, 1H, H-2), 5.99 (bd, *J* = 10.2 Hz, 1H, H-3$_\alpha$), 7.35-7.43 (m, 6H, C$_6$H$_5$), 7.69-7.72 (m, 4H, C$_6$H$_5$); β anomer (in the mixture of α and β anomers) δ 1.04 (s, 9 H, CMe$_3$), 1.19 (dd, J = 7.2 and 6.8 Hz, 3H, CH$_2$C*H*$_3$), 1.28 (s, 3H, CH$_3$), 1.52 (s, 3H, CH$_3$), 3.51 (dq, J = 9.8 and 6.8 Hz, 1H, C*H*$_2$CH$_3$), 3.60 (dd, J = 10.2 and 2.9 Hz, 1H, H-5'), 3.64 (dd, J = 10.2 and 3.4 Hz, 1H, H-5'), 3.80 (dq, J = 9.8 and 7.2 Hz, 1H, C*H*$_2$CH$_3$), 3.83-3.89 (m, 3H, H-5, H-6), 4.03 (d, J = 10.8 Hz, 1H, OH), 4.21 (d, J = 9.3 Hz, 1H, H-4), 4.30 (bs, 1H, H-4'), 4.44 (d, J = 5.9 Hz, 1H, H-2'), 4.60 (d, J = 5.9 Hz, 1H, H-3'), 5.00 (bs, 1H, H-1), 5.27 (d, J = 10.8 Hz, 1H, H-1'), 5.83 (dm, J = 10.2 Hz, 1H, H-2), 5.97 (bd, J = 10.2 Hz, 1H, H-3), 7.35-7.43 (m, 6H, C$_6$H$_5$), 7.69-7.72 (m, 4H, C$_6$H$_5$); ^{13}C NMR (50.3 MHz) α anomer (in the mixture of α and β anomers) δ 15.30 (*C*H$_3$CH$_2$), 19.28 (C*Me*$_2$), 24.64 (C*Me*$_3$), 26.11 (C*Me*$_2$), 26.76 (C*Me*$_3$), 63.54 (*C*H$_2$CH$_3$), 63.83 (C-6), 70.07 and 71.14 (C-4, C-5), 70.28 (C-5'), 79.30, 79.62 and 81.75 (C-2', C-3' and C-4'), 93.95 (C-1), 97.78 (C-1'), 113.11 (*C*Me$_2$), 127.51-135.78 (C-2, C-3, C$_6$H$_5$); β anomer (in the mixture of α and β anomers) δ 15.24 (*C*H$_3$CH$_2$), 19.32 (C*Me*$_2$), 24.91 (C*Me*$_3$), 26.47 (C*Me*$_2$), 26.79 (C*Me*$_3$), 63.29 (*C*H$_2$CH$_3$), 63.93 (C-6), 69.39 and 71.32 (C-4, C-5), 69.56 (C-5'), 81.90, 85.66 and 87.14 (C-2', C-3' and C-4'), 93.88 (C-1), 103.46 (C-1'), 112.17 (*C*Me$_2$), 127.51-135.78 (C-2, C-3, C$_6$H$_5$).

Anal. Calcd for $C_{32}H_{44}O_8Si$ (584.79): C, 65.73; H, 7.58. Found: C, 65.57; H, 7.71.

(Ethyl 6-*O*-*tert*-Butyldiphenylsilyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranos-4-yl) 5-*O*-(Ethyl 6-*O*-*tert*-Butyldiphenylsilyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranos-4-yl)-2,3-*O*-isopropylidene-α-D-ribofuranoside

(16). Yield 30 % ; oil; R_f 0.75 (dichloromethane/petroleum ether/diethyl ether 4:3:1 v/v); $[\alpha]_D^{20}$ +24.3 (*c* 1, chloroform); ^{1}H NMR (500 MHz) δ 1.04 (s, 9H, CMe_3), 1.05 (s, 9H, CMe_3), 1.19 (t, J = 7.1 Hz, 3H, CH_2CH_3), 1.20 (t, J = 7.1 Hz, 3H, CH_2CH_3), 1.26 (s, 3H, CH_3), 1.43 (s, 3H, CH_3), 3.31 (dd, J = 9.2 and 9.2 Hz, 1H, H-5'), 3.51 (dq, J = 9.6 and 7.1 Hz, 1H, CH_2CH_3), 3.53 (dq, J = 9.6 and 7.1 Hz, 1H, CH_2CH_3), 3.67 (dd, J = 9.2 and 6.4 Hz, 1H, H-5'), 3.74-3.89 (m, 8 H, CH_2CH_3, 2 x H-5, 4 x H-6), 3.97 (bd, J = 9.3 Hz, 1H, $H\text{-}4_{anom}$), 4.21-4.25 (m, 1 H, H-4'), 4.22 (bd, J = 8.9 Hz, 1H, $H\text{-}4_{pos\ 5}$), 4.36 (d, J = 6.0 Hz, 1H, H-2' or H-3'), 4.49 (d, J = 6.0 Hz, 1H, H-2' or H-3'), 4.98 (s, 1H, H-1), 5.01 (s, 1H, H-1), 5.20 (s, 1H, H-1'), 5.66 (bd, J = 10.3 Hz, 1H, H-2), 5.77 (bd, J = 10.3 Hz, 1H, H-2), 6.02 (d, J = 10.3 Hz, 1H, H-3), 6.05 (d, J = 10.3 Hz, 1H, H-3), 7.35-7.41 (m, 12H, C_6H_5), 7.64-7.75 (m, 8H, C_6H_5); ^{13}C NMR (50.3 MHz) δ 15.29 (2 x CH_2CH_3), 19.30 (2 x CMe_3), 25.22 (CMe_2), 26.55 (CMe_2), 26.75 (CMe_3), 26.80 (CMe_3), 63.11, 63.50, 63.60 and 63.72 (2 x CH_2CH_3 and 2 x C-6), 69.84 (C-5'), 70.48, 70.67, 71.25 and 71.84 (2 x C-4, 2 x C-5), 82.16, 85.41 and 85.41 (C-2', C-3', C-4'), 94.08 (2 x C-1), 110.61 (C-1'), 112.42 (CMe_2), 126.55, 126.97, 127.57, 127.66, 129.55, 130.25, 132.27, 133.26, 133.45, 133.55, 133.81, 135.64 and 135.82 (C-2, C-3 and C_6H_5).

Anal. Calcd for $C_{56}H_{74}O_{11}Si_2$ (979.38): C, 68.68; H, 7.62. Found: C, 69.51; H, 7.67.

Ethyl 6-*O*-*tert*-Butyldiphenylsilyl-4-*O*-(2,3;5,6-di-*O*-isopropylidene-α-D-mannofuranosyl)-2,3-dideoxy-α-D-*threo*-hex-2-enopyranoside (17a). Yield 21 % ; oil; R_f 0.53 (dichloromethane/hexane/diethyl ether 4:1:3 v/v); $[\alpha]_D^{20}$ -26.8 (*c* 1, chloroform); ^{1}H NMR (300 MHz) δ 1.05 (s, 9H, CMe_3), 1.16 (t, J = 7.1 Hz, 3H, CH_2CH_3), 1.32 (s, 3H, CH_3), 1.38 (s, 3H, CH_3), 1.43 (s, 6H, CH_3), 3.47 (dq, J = 9.7 and 7.1 Hz, 1H, CH_2CH_3), 3.71 (dq, J = 9.7 and 7.1 Hz, 1H, CH_2CH_3), 3.73 (dd, J = 9.9 and 5.8 Hz, 1H, H-6), 3.87 (dd, J = 9.9 and 7.8 Hz, 1H, H-6), 3.91 (dd, J = 5.3 and 2.4 Hz, 1H, H-4), 4.00 (dd, J = 6.9 and 3.6 Hz, 1H, H-4'), 4.03 (dd, J = 8.7 and 4.7 Hz, 1H, H-6'), 4.12 (dd, J = 8.7 and 6.5 Hz, 1H, H-6'), 4.15 (ddd, J = 7.8, 5.8 and 2.4 Hz, 1H, H-5), 4.41 (ddd, J = 6.9, 6.5 and 4.7 Hz, 1H, H-5'), 4.60 (d, J = 5.9 Hz, 1H, H-2'), 4.73 (dd, J = 5.9 and 3.6 Hz, 1H, H-3'), 4.98 (d, J = 3.1 Hz, 1H, H-1), 5.25 (s, 1H, H-1'), 5.92 (dd, J = 10.1 and 3.1 Hz, 1H, H-2), 6.12 (dd, J = 10.1 and 5.3 Hz, 1H, H-3), 7.26-7.44 (m, 6H, C_6H_5), 7.66-7.72 (m, 4H, C_6H_5); ^{13}C NMR (50.3 MHz) δ 15.27 (CH_3CH_2), 19.12 (CMe_3), 24.71 (CH_3), 25.21 (CH_3), 25.93 (CH_3), 26.80 (CH_3, CMe_3), 62.38 and 63.59 (C-6, CH_2CH_3), 66.78 (C-6'), 67.76 and 69.90 (C-4, C-5), 73.24 (C-5'), 79.66 and 80.23 (C-4', C-3'), 84.85 (C-2'), 93.78 (C-1), 108.14 (C-1'), 109.12 and 112.59 (CMe_2), 127.74, 128.84, 129.74, 129.79, 133.10, 135.55 and 135.57 ((C-2, C-3, C_6H_5).

Anal. Calcd for $C_{36}H_{50}O_9Si$ (654.88): C, 66.06; H, 7.65. Found: C, 65.68; H, 7.78.

Ethyl 6-*O*-*tert*-Butyldiphenylsilyl-2-*O*-(2,3;5,6-di-*O*-isopropylidene-α-D-mannofuranosyl)-3,4-dideoxy-α-D-*threo*-hex-3-enopyranoside (18a). Yield 61 % ; oil; R*f* 0.68 (dichloromethane/hexane/diethyl ether 4:3:1 v/v); $[\alpha]_D^{20}$ +75.6 (*c* 0.9, chloroform); ^1H NMR (500 MHz) δ 1.05 (s, 9H, CMe_3), 1.20 (t, J = 7.1, 3H, CH_2CH_3), 1.30 (s, 3H, CH_3), 1.37 (s, 3H, CH_3), 1.44 (s, 3H, CH_3), 1.45 (s, 3H, CH_3), 3.54 (dq, J = 9.6 and 7.1 Hz, 1H, CH_2CH_3), 3.69 (dd, J = 10.1 and 6.9 Hz, 1H, H-6), 3.74 (dq, J = 9.6 and 7.1 Hz, 1H, CH_2CH_3), 3.81 (d, J = 4.6 Hz, 1H, H-2), 4.01 (dd, J = 8.6 and 5.1 Hz, 1H, H-6'), 4.02 (dd, J = 6.5 and 3.6 Hz, 1H, H-4'), 4.11 (dd, J = 8.6 and 6.4 Hz, 1H, H-6'), 4.15-4.20 (m, 1 H, H-5), 4.39 (ddd, 1 H, J = 6.5, 6.4 and 5.1 Hz, 1H, H-5'), 4.60 (d, 1 H, J = 5.8 Hz, 1H, H-2'), 4.75 (dd, 1 H, J = 5.8 and 3.6 Hz, 1H, H-3'), 4.85 (s, 1H, H-1), 5.18 (s, 1H, H-1'), 5.91 (bdd, J = 10.5 and 4.6 Hz, 1H, H-3), 6.14 (d, J = 10.5 Hz, 1H, H-4), 7.26-7.45 (m, 6H, C_6H_5), 7.65-7.73 (m, 4H, C_6H_5); ^{13}C NMR (75 MHz) δ 15.11 (CH_3CH_2), 19.27 (CMe_3), 24.48 (CH_3), 25.18 (CH_3), 25.87 (CH_3), 26.83 (CH_3, CMe_3), 63.79 (C-6), 65.84 (CH_2CH_3), 66.83 (C-6'), 68.42 (C-5), 69.46 (C-2), 73.17 (C-5'), 79.57 (C-3'), 80.41 (C-4'), 85.26 (C-2'), 98.24 (C-1), 105.63 (C-1'), 109.15 (CMe_2), 112.53 (CMe_2), 121.69 (C-3), 131.90 (C-4), 127.67, 129.69, 133.47, 133.49 and 135.63 (C_6H_5).

Anal. Calcd for $C_{36}H_{50}O_9Si$ (654.88): C, 66.06; H, 7.65. Found: C, 65.97; H, 7.81.

Ethyl 6-*O*-*tert*-Butyldiphenylsilyl-2-*O*-(1,2;5,6-di-*O*-isopropylidene-α-D-glucofuranos-3-yl)-3,4-dideoxy-α-D-*threo*-hex-3-enopyranoside (18b). Yield 76 % ; oil; R*f* 0.65 (dichloromethane/hexane/diethyl ether 4:3:1 v/v); $[\alpha]_D^{20}$ +28.4 (*c* 1.0, chloroform); ^1H NMR (500 MHz) δ 1.05 (s, 9H, CMe_3), 1.20 (t, J = 7.1 Hz, 3H, CH_2CH_3) , 1.28 (s, 3H, CH_3), 1.31 (s, 3H, CH_3), 1.40 (s, 3H, CH_3), 1.47 (s, 3H, CH_3), 3.52 (dq, J = 9.6 and 7.1 Hz, 1H, CH_2CH_3), 3.68 (dd, J = 10.1 and 6.5 Hz, 1H, H-6), 3.74 (dq, J = 9.6 and 7.1 Hz, 1H, CH_2CH_3), 3.75 (m, 1H, H-2), 3.80 (dd, J = 10.1 and 5.8 Hz, 1H, H-6), 3.92 (dd, J = 8.3 and 6.2 Hz, 1H, H-6'), 4.05 (dd, *J* = 8.3 and 6.2 Hz, 1H, H-6'), 4.09 (dd, J = 7.4 and 2.9 Hz, 1H, H-4'), 4.13 (d, J = 2.9 Hz, 1H, H-3'), 4.18 (m, 1H, H-5), 4.29 (ddd, J = 7.4, 6.2 and 6.2 Hz, 1H, H-5'), 4.47 (d, J = 3.5 Hz, 1H, H-2'), 4.91 (s, 1H, H-1), 5.84 (d, J = 3.5 Hz, 1H, H-1'), 5.85 (dm, J = 10.7 Hz, 1H, H-3), 6.10 (d, J = 10.7 Hz, 1H, H-4), 7.24-7.42 (m, 6H, C_6H_5), 7.64-7.66 (m, 4H, C_6H_5); ^{13}C NMR (50.3 MHz) δ 15.10 (CH_2CH_3), 19.25 (CMe_3), 25.39 (CH_3), 26.29 (CH_3), 26.81 (CH_3, CMe_3), 26.86 (CH_3), 63.68 (CH_2CH_3), 65.75 (C-6), 67.35 (C-6'), 68.94, 72.03 and 72.41 (C-2, C-5, C-5'), 80.86 and 81.20 (C-3', C-4'),

83.81 (C-2'), 98.19 (C-1), 105.32 (C-1'), 108.84 (CMe_2), 111.81 (CMe_2), 122.77 (C-3), 131.55 (C-4), 127.67, 129.70, 129.72, 133.39, 133.42, 135.58, 135.63 (C_6H_5).

Anal. Calcd for $C_{36}H_{50}O_9Si$ (654.88): C, 66.06; H, 7.65. Found: C, 65.85; H, 7.64.

ACKNOWLEDGMENTS

This work was supported by a grant awarded to S. P. by the Région Rhône-Alpes and a fellowship to I. F. by the M.E.S.R.

REFERENCES

1. a) G. Wulff and G. Röhle, *Angew. Chem., Int. Ed. Engl.*, **13**, 157 (1974). b) A. F. Bochkov and G. E. Zaikov, *Chemistry of the O-Glycosidic Bond: Formation and Cleavage*; Pergamon Press, Oxford, 1979. c) H. Paulsen, *Angew. Chem., Int. Ed. Engl.*, **21**, 155 (1982). d) H. Paulsen, *Chem. Soc. Rev.*, **13**, 15 (1984). e) R. R. Schmidt, *Angew. Chem., Int. Ed. Engl.*, **25**, 212 (1985). f) H. Kunz, *Angew. Chem., Int. Ed. Engl.*, **26**, 294 (1987). g) R. R. Schmidt, *Pure Appl. Chem.*, **61**, 1257 (1989). h) R. R. Schmidt in *Comprehensive Organic Synthesis*, Vol. 6; B. M. Trost, I. Fleming and E. Winterfeldt, Ed.; Pergamon Press, Oxford, 1991, p 33. i) P. Sinay, *Pure Appl. Chem.*, **63**, 519 (1991). j) J. Banoub, P. Boullanger and D. Lafont, *Chem. Rev.*, **92**, 1167 (1992). k) K. Toshima and K. Tatsuta, *Chem. Rev.*, **93**, 1503 (1993).
2. a) W. N. Haworth, E. L. Hitot and R. J. W. Reynolds, *J. Chem. Soc.*, 302 (1934). b) W. T. Haskins, R. M. Hann and C. S. Hudson, *J. Am. Chem. Soc.*, **64**, 1852 (1942).
3. R. J. Ferrier and N. Prasad, *J. Chem. Soc. (C)*, 570 (1969).
4. a) S. J. Danishefsky and M. P. De Ninno, *Angew. Chem., Int. Ed. Engl.*, **26**, 15 (1987). b) R. L. Halcomb and S. J. Danishefsky, *J. Am. Chem. Soc.*, **111**, 6661 (1989). c) D. A. Griffith and S. J. Danishefsky, *J. Am. Chem. Soc.*, **113**, 5863 (1991).
5. a) A. M. Gomez, S. Valverde and B. Fraser-Reid, *J. Chem. Soc., Chem. Commun.*, 1207 (1991). b) J. C. Lopez and B. Fraser-Reid, *J. Chem. Soc., Chem. Commun.*, 94 (1992). c) J. C. Lopez, A. M. Gomez, S. Valverde and B. Fraser-Reid, *J. Org. Chem.*, **60**, 3851 (1995).
6. K. Takeda, H. Nakamura, A. Ayabe, A. Akiyama, Y. Harigaya and Y. Mizuno, *Tetrahedron Lett.*, **35**, 125 (1994).
7. a) R. Lakhmiri, P. Lhoste, P. Boullanger and D. Sinou, *J. Chem. Res. (S)*, 342 (1990), *(M)*, 2301 (1990). b) C. Goux, P. Lhoste and D. Sinou, *Synlett*, 725 (1992). c) R. Lakhmiri, P. Lhoste, B. Kryczka and D. Sinou, *J. Carbohydr. Chem.*, **12**, 223 (1993).
8. D. Sinou, I. Frappa, P. Lhoste, S. Porwanski and B. Kryczka, *Tetrahedron Lett.*, **36**, 1251 (1995).
9. a) R. R. Schmidt and M. Reichrath, *Angew. Chem., Int. Ed. Engl.*, **18**, 466 (1979). b) R. R. Schmidt, M. Reichrath and U. Mœring, *Tetrahedron Lett.*, **21**, 3561 (1980). c) R. R. Schmidt, U. Mœring and M. Reichrath, *Chem. Ber.*, **115**, 39 (1982). d) R. R. Schmidt, U. Mœring and M. Reichrath, *Tetrahedron Lett.*, **21**, 3565 (1980). e) R. R. Schmidt, M. Reichrath and U. Mœring, *J. Carbohydr. Chem.*, **3**, 67 (1984). f) J. J. Oltvoort, M. Kloosterman, C. A. A. Van Bœckel and J. H. Van Boom, *Carbohydr. Res.*, **130**, 147 (1984).

10. G. Zemplèn, *Ber. Dtsch. Chem. Ges.*, **60**, 1555 (1927).
11. C. Goux, M. Massacret, P. Lhoste and D. Sinou, *Organometallics*, **14**, 4585 (1995).
12. H. H. Baer and Z. S. Hanna, *Can. J. Chem.*, **51**, 889 (1981).
13. J. B. Stothers in *Carbon-13 NMR Spectroscopy*, Academic Press, New York, 1973, Chap 3.
14. K. Block and C. Pedersen, *Adv. Carbohydr. Chem. Biochem.*, **41**, 27 (1983).
15. P. E. Pfeffer, G. G. Moore, P. D. Hoagland and E. S. Rothman in *Synthetic Methods for Carbohydrates*, Vol. 39; H. S. El Khadem, Ed.; American Chemical Society, Symposium Series, 1976, p 155.
16. C. A. Tolman, *Chem. Rev.*, **77**, 327 (1977).
17. a) E. Breitmaier, W. Vœlter, G. Jung and C. Tänzer, *Chem. Ber.*, **104**, 1147 (1971). b) K. Mizutani, R. Kasai and O. Tanaka, *Carbohydr. Res.*, **87**, 19 (1980). c) W. Vœlter and E. Breitmaier, *Org. Magn. Reson.*, **5**, 311 (1973).
18. S. De Bernardo and M. Weigele, *J. Org. Chem.*, **41**, 287 (1976).
19. O. Th. Schmidt in *Methods in Carbohydrate Chemistry*, Vol. II; R. L. Whistler and M. L. Wolfrom, Eds.; Academic Press Inc.; New York, 1963, p 318.
20. J. Gelas and D. Horton, *Carbohydr. Res.*, **45**, 181 (1975).