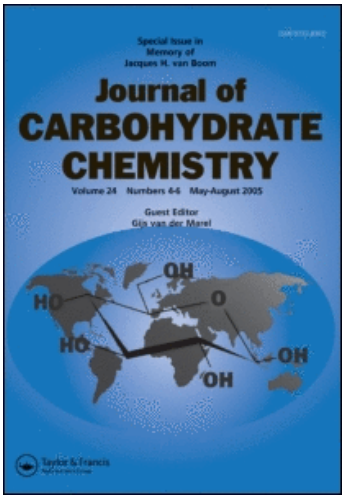

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SYNTHESIS AND REARRANGEMENT REACTIONS OF C-ALKYLIDENE CARBOHYDRATES

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ABSTRACT

Direct olefinations on one hand in comparison to eliminations of aldols of various uloses on the other each proved to be specific as to the site of unsaturation in the branched-chain products, found to be interconvertible with one exception under a variety of conditions. Although shown to be generally equivalent to its Wittig-counterpart, the Peterson reagent employed is liable to cause eliminations in the initial olefin. One of the branched-chain products appears to be of unusual molecular rigidity as evidenced by a large ^5J coupling.

INTRODUCTION

A considerable part of carbohydrate chemistry is carbonyl-chemistry, involving such educts as hemiacetals, halogenoses, enol derivatives, carboxylic esters and lactones, aldehydes and above all ketones, the so-called uloses, particularly useful in various types of chemical transformations.[1-3] The respectable progress in highly stereoselective C-C-bond forming methodology in recent years, allowing even total syntheses of carbohydrates[4], is distinctly influencing the preparative potential of carbohydrate carbonyl derivatives, the stereospecific branching being of particular interest.[5,6]

As a result of our recent investigations, regarding novel C-C-bond forming reactions, we described the stereospecific formation

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of carbohydrate derived ß-hydroxy esters by the aldolization of various uloses employing ethyl trimethylsilylacetate (ETSA) in the presence of tetra-n-butyl-ammonium fluoride (TBAF).[7] These reactions are without precedence, inasmuch as ketones, including cyclic ketones, with this combination of reagents are reported to form O-trimethylsilyl enol ethers, exclusively.[8,9] Because of this obviously educt-dependent behavior of ETSA-enolate anion, which in the form of its lithium salt also converts carbonyl compounds into olefins (Peterson-reaction) [10,11] and because of the well-known elimination reaction of ß-hydroxy- to α,β-unsatured esters, a comparative investigation of the branching of uloses by Peterson as well as Wittig reactions on one hand, and by Reformatzky and the above mentioned ETSA/TBAF-reagents on the other hand appeared to be of interest.[12-15]

In view of the paucity of reports on applications of the Peterson-olefination to carbohydrates,[16-18] the present study was undertaken to obtain information on the elimination pattern of carbohydrate derived ß-hydroxy esters, as well as to compare the Peterson olefinations employing Li-ETSA to Wittig reactions with various uloses.

RESULTS AND DISCUSSION

Wittig- and Peterson-Olefination

Methyl 4,6-O-benzylidene-2,3-dideoxy-(E)-3-C-ethoxycarbonylmethylene-α-D-erythro- hexopyranoside (4), obtained in 95 % yield from methyl 4,6-O-benzylidene-2-deoxy-α-D-erythro-3-hexulopyranoside (1)[19] with triphenylethyloxycarbonylmethylenephosphorane, was also formed from 1 with lithio-ETSA, although in lower yield. In the latter case, product 4 was accompanied by a mixture of by products amounting to a total of 20%, one of them, ca. 15%, was found to be 1,5-anhydro-4,6-O-benzylidene-2,3-dideoxy-(E)-3-C-ethoxycarbonylmethylene-α-D-erythro-hex-1-enitol (6). The formation of this product may be explained by either one of two consecutive reactions. First, part of the educt 1 with Li-ETSA suffers elimination with formation of the intermediate 1,5-anhydro-4,6-O-benzylidene-2,3-dideoxy-α-D-erythro-

hex-3-ulo-1-enitol (7), being subject to olefination with formation of 6. Simultaneously the remaining 1 with Li-ETSA gives 4, thus accounting for the mixture of products observed. Second, the by-product 6 is obtained by an elimination of the initial formed 4. The latter sequence was found to be correct.

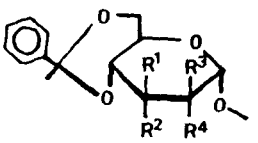
When compound 4 was subjected to equimolar amounts of either lithium diisopropylamide (LDA) or potassium-tert-butoxide at -78°C, followed by warming each of the reaction mixtures at 0°C, 6 was obtained exclusively in yields of 60 % and 68 %, respectively. Likewise, treatment of 1 with a two-molar amount of Li-ETSA gave 6 in a yield of 72 %. While the formation of 4 by Wittig-reaction and of 4 and 6 by Peterson-reactions all proceed quite rapidly, both olefinations are comparatively slow with compound 7[21], with the Wittig-reaction showing a dramatically lower rate. Thus, compound 4 rather than 7 is the intermediate in the two-step-formation of 6.

Peterson olefination also appeared to be applicable to methyl 4,6-O-benzylidene-3-deoxy-α-D-erythro-2-hexulopyranoside (2)[19] as well as to 3,6-anhydro-1,2-O-isopropylidene-α-D-xylo-5-hexulofuranose (3) yielding the corresponding C-ethyloxycarbonylmethylene derivatives (5) and a mixture of the stereoisomers (3c) and (3d), respectively.[23] With both educts, Wittig-olefinations gave the higher yields.

Elimination and Rearrangements Reactions

Since both direct olefinations of the uloses invariably yield identical products, a study of their aldolization products, readily accessible with the ETSA/TBAF-reagent[7] or by Reformatzky-reaction[14], appeared to be indicated. Inasmuch as acid-catalyzed reactions are incompatible with the protecting groups in the educts (1a), (2a), and (3a),[7] base-catalyzed eliminations of their respective sulfonates, preferably triflates [25,26] (1b), (2b), and (3b), were performed. Although such bases as pyridine, triethylamine and DBU were appropriate, good yields of the elimination products (1c), (2c), and (3c) were obtained with TBAF-trihydrate. This result is in accordance with eliminations frequently paralleling attempted substitution of triflates with fluoride as a nucleophile.[32]

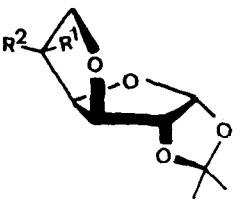
While the elimination products 1c and 2c are each isomeric to



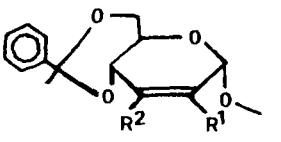
No	R^1	R^2	R^3	R^4
1	=O		H	H
2	H	H	=O	
1a	R	OH	H	H
1b	Otfl	R	H	H
1d	OH	R	H	H
2a	H	H	OH	R
2b	H	H	Otfl	R
2d	H	H	R	OH
4	=CHCOOEt (Z)		H	H
5	H	H	=CHCOOEt (E)	

R=$-CH_2COOEt$

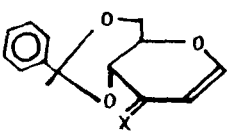
Otfl=$-O-SO_2-CF_3$



No	R^1	R^2
3	=O	
3a	OH	CH_2COOEt
3b	Otfl	CH_2COOEt
3c	=CHCOOEt (E)	
3d	=CHCOOEt (Z)	

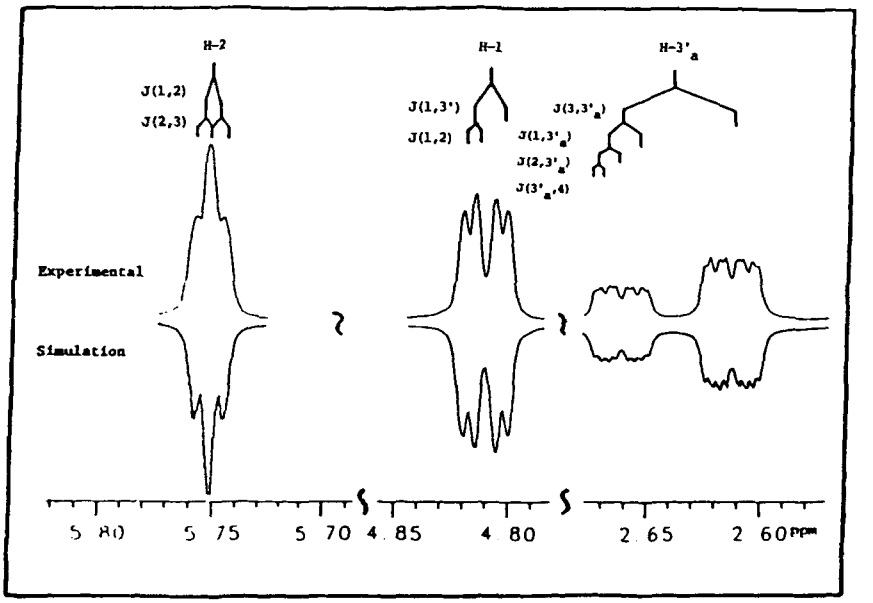


No	R^1	R^2
1c	H	CH_2COOEt
2c	CH_2COOEt	H



No	X
6	=CHCOOEt (E)
7	=O

FIG. 1



Part of the 300 MHz ^{1}H-NMR-spectrum of 1c; the coupling pattern of H-1, H-2, and H-3'a is shown in detail; noteworthy is the large homoallylic coupling between H-1 and H-3'a (in comparison with the corresponding part of the simulated spectrum-lower trace; PANIC).

those of the direct olefinations of 1 and 2, respectively, compound 3, independent of the method applied, always forms a single product. As in carbocyclic rings, the reason for this result is most likely the greater thermodynamic stability of an endocyclic as compared to an exocyclic double bond in 6-membered and vice versa in 5-membered rings.[27] This explanation is experimentally supported by the facile rearrangement of both 4 and 5 by heating in pyridine into 1c and 2c, respectively. While their reverse reactions can only be accomplished by strong bases as exemplified by potassium-tert -butoxide, compound 3c completely resists all attempts to alter its structure. There is a noteworthy, extraordinary homoallylic ^{5}J coupling between H-1 and H-3'a of considerable magnitude of 4.25 Hz in compound 1c, best explained by a very rigid "W"-conformation in this part of the molecule [30,31] (cf. FIG.2).

Inasmuch as the ethoxycarbonylmethyl substituents in 1a and 2a were found to be equatorially orientated as previously described,[7, 28]

TABLE 1

Product distribution and physical properties of Reformatzky-reaction products

educt	conditions[a]	products/yield (%)		mp	$[\alpha]_D^{20}$ (c)[b]
1	DMM/THF 1/1	1a	85	90-91	72.0 (c 0.2)
	30 min;refl.	1d	5	oil	63.5 (c 0.3)
1	DMM/THF 10/1	1a	75		
	25 min;refl.	1d	0		
1	THF	1a	30		
	30 min;refl.	1d	0		
1	THF/BENZ 1/1	1a	10		
	30 min;refl.	1d	0		
1	TMB	1a	0		
	300 min;25°C	1d	0		
2	DMM	2a	74	87-90	58.2 (c 8.5)
	25 min;refl.	2d	9	oil	47.3 (c 2.0)
3	DMM	3a	78	76-79	10.2 (c 1.5)
	20 min;refl.				

a DMM stands for methylal, THF for tetrahydrofuran, BENZ for benzene, and TMB for trimethyl borate
b all optical rotations described in this work were taken in $CHCl_3$

their respective stereoisomers (1d) and (2d), obtained by Reformatzky-reactions are necessarily in axial positions.

Because of the general progress in Reformatzky-reactions through the application of more suitable solvents,[14,28,29] hitherto scarcely applied in carbohydrate chemistry, compounds 1, 2, and 3 were subjected to such reactions under various conditions. The results summarized in Table 1 indicate the solvent dependence of the yields as well as the distribution of stereoisomers obtained under various conditions. Whenever applicable, methylal appears to be prefered over other solvents.

EXPERIMENTAL

General Methods. The melting points are uncorrected (Tottoli-apparatus); optical rotations were taken with a Perkin-Elmer 141 polarimeter, and NMR-spectra were recorded in $CDCl_3$ with TMS as internal standard on a Bruker WH-90, AM-250, Varian XL-200 and a General Electric QE-300 instrument; TLC was performed on precoated silica gel sheets (Merck, No 5554) and Merck silica gel F60 was used for column chromatography.[33]

General procedures for Wittig- and Peterson Olefinations for the Synthesis of

3,6-Anhydro-5-deoxy-(Z)(and (E))-5-C-ethoxycarbonylmethylene-1,2-O-isopropylidene-α-D-xylo-hexofuranose 3d (and 3c) from 3, methyl 4,6-O-benzylidene-2,3-dideoxy-(Z)-3-C-(or 2-C-)-ethoxycarbonyl-methylene-α-D-erythro- hexopyranoside 4 (or 5) from 1 (or 2), 1,5-anhydro-4,6-O-benzylidene-2,3-dideoxy-(E)-3-C-ethoxycarbonyl-methylene-α-D-erythro-hex-1-enitol 6 (from 7)

A) Wittig-reactions

To each solution of 4.0 mmol of 1, 2, 3, and 7 respectively, in 15 ml anhyd chloroform a solution of 2.1 g (6 mmol) of triphenyl-ethoxycarbonylmethylenephosphorane in 5 ml of anhyd chloroform was added. After completion of the reactions (TLC; 1h for educts 1, 2, and 3, 60 h for 7) the solvent was evaporated and the products were purified by chromatography.

B) Peterson-reactions

LDA was prepared by adding 0.61 g (6mmol) freshly distilled diisopropylamine to 2.8 ml of n-butyl lithium (1.8 M in hexane) at -10°C under dry nitrogen. After stirring for 5 min. at this temp, the reaction mixture was cooled to -78°C, and 0.1 g (6 mmol) ETSA was injected. After 10 min. each 4 mmol of 1, 2, 3 or 7, respectively in ca 15 ml anhyd THF was slowly added dropwise. After stirring for an additional 10 min. at -78°C, the mixture was allowed to warm to room temperature, then finally quenched by 10 ml of water. After

TABLE 2

Physical properties of ethoxycarbonylmethylene-branched products 3c/3d, 4, 5, and 6

educt	product	method	yield (%)	mp (°C)	$[\alpha]_D^{20}$ (c)[a]	R_f[b]
1	4	A	95	124-129	195.0 (c 0.7)	0.66
1	4	B	60			
2	5	A	95	102-104	20.2 (c 1.1)	0.66[c]
2	5	B	62			
3	3c	A	50	3d: 98-100	61.0 (c 2.0)	0.51
3	3d		45			
3	3c	B	47	3c: oil	86.7 (c 3.1)	0.39
3	3d		27			
7	6	A	76	107-108	117.0 (c 3.6)	0.88
7	6	B	68			

a all taken in $CHCl_3$

b toluene/ethyl acetate 4/1

c according to NMR ca. 3-5 % contaminated by the (Z)-isomer, inseparable by either crystallization or chromatography.

d method A: Wittig-reaction; method B: Peterson-olefination

separation of the organic layer, the aq layer was extracted with ether (3 x 25 ml). The combined organic phases were dried (Na_2SO_4) and evaporated. The respective products were subjected to column chromatography.

1,5-anhydro-4,6-O-benzylidene-2,3-dideoxy-(E)-3-C-ethoxycarbonylmethylene-α-D-erythro-hex-1-enitol (6)directly from 1.

To LDA from 1.22 g (12 mmol) of diisopropylamine and 4.6 ml (10 mmol) of n-butyl lithium (1.8 M in hexane) at -78°C, 2.0 g (12 mmol) of ETSA was injected, and after 10 min. a suspension of 1.05 g (4 mmol) of 1 in 15 ml of abs THF was slowly added. After stirring at -78°C for 5 min., the mixture was allowed to warm to room temp. After 30 min. at room temp, 10 ml of water were added, and the separated aq layer was extracted with ether (3 x 25 ml). The combined organic layer was dried (Na_2SO_4), evaporated, and the residue purified by chromatography. Yield: 0.87 g of 6 (72 %); data cf. table 2.

TABLE 3

Physical data of the products 1c, 2c, 3c/3d

educt	product	yield (%)	mp (°C)	$[\alpha]_D^{20}$ (c)[a]	R_f[b]
4	1c	53	50-52	29 (c 0.9)	0.41
1a	1c	77			
5	2c	56	57-58	28 (c 2.9)	0.53
2a	2c	74			
3a	3c/3d	53/42	cf. tab. 2		

a all taken in $CHCl_3$
b toluene/ethyl acetate 4/1

General procedure for the synthesis of (1c), and (2c) by rearrangements of 4 and 5, respectively.

Methyl 4,6-O-benzylidene-2,3-dideoxy-3-C-ethoxycarbonylmethyl-α-D-erythro-hex-2-enopyranoside (1c), and methyl 4,6-O-benzylidene-2,3-dideoxy-2-C-ethoxycarbonylmethyl-α-D-erythro-hex-2-enopyranoside (2c)

1.5 mmol of the educts 4 or 5 in 8 ml abs pyridine each were heated under reflux for ca. 60 h, the solvent removed by azeotropic distillation with toluene (5 x 10 ml) and the respective residue purified by chromatography

General procedure for the synthesis of 1c, 2c and 3c/3d via aldol triflates 1b, 2b, and 3b, respectively.

Each 3 mmol of the educts 1a, 2a, and 3a in 15 ml of anhyd chloroform and 5 ml of anhyd pyridine were all treated with 1.13 g (4 mmol) of trifluoromethanesulfonic anhydride in 5 ml of abs chloroform at -10°C and stirred for 5 h at room temperature. After usual work-up [34] the solutions of each 1b, 2b, and 3b in 10 ml of anhyd chloroform without further purification were treated with 1.27 g (4 mmol) of TBAF. 3 H_2O over a period of 20 min. and the reaction mixtures were extracted twice with 5 ml of water, dried (Na_2SO_4), and evaporated. The products were purified by chromatography.

Reformation of 4 and 5 from 1c and 2c, respectively

To a solution of 0.5 g (1.5 mmol) of 1c and 2c in 5 ml of abs dimethylsulfoxide each, 0.17 g (1.5 mmol) of potassium-tert.-butoxide were added, the mixture stirred at 0°C for 30 min. and then slowly poured into 250 ml of ether under vigorous stirring. After washing with water and brine, drying over Na_2SO_4, and evaporation, the corresponding residues were subjected to chromatography to yield 4 (0.41 g, 82 %) and 5 (0.39 g, 77 %), the physical data of which are summarized in table 2.

General procedure for Reformatzky-reactions. Synthesis of methyl 4,6-O-benzylidene-2-deoxy-3-C-ethoxycarbonylmethyl-α-D-ribo-(-arabino-)-hexopyranoside 1a (1d) from 1, methyl 4,6-O-benzylidene-3-deoxy-2-C-ethoxycarbonylmethyl-α-D-arabino-(-ribo-)-hexopyranoside 2a (2d) from 2, and 3,6-anhydro-5-C-ethoxycarbonylmethyl-1,2-O-isopropylidene-α-D-gluco-furanose (3a) from 3

2.1 g (72 mmol) of Zn-dust suspended in 20 ml of solvent (cf. table 1) containing a catalytic amount of iodine were heated under reflux for 10 min., and 0.5 g (30 mmol) of ethyl bromoacetate in 5 ml of the same solvent were so added to maintain the mixture under slight reflux. For completion the reaction was refluxed for 10 min. and finally each 4 mmol of the educts in 20 ml of solvent were added. After refluxing for 20-30 min. (cf. table 1) the reaction mixtures were cooled, poured into 120 ml of aq NaH_2PO_4 soln, filtered and the layers separated. The aq layers were extracted twice with ether (50 ml each), the combined organic phase was dried over Na_2SO_4, and evaporated yielding semicrystalline solids which were subjected to chromatography; the physical properties and yields are summarized in table 1.

TABLE 4

^{1}H-NMR-spectroscopic data

No	H-1	H-2	H-3	H-4	H-5	H-6$_A$ §	H-6$_B$	CH-R^a	CH$_2$ ^{b}	CH$_3$ ^{b}	CH ^{c}	OMe	aromat	B$_o$
1c	4.81	5.75	---	4.24 - 4.31		3.77 - 3.98		AB 2.48 2.63	3.77	0.99	5.61	3.19	7.3-7.5	300
	^3J(H-1,H-2)= 2.0; ^2J(CH-R,AB)= 14.5; ^3J(CH$_3$-CH$_2$)= 6.95; ^4J(H-2, H-3')= 2.0; ^4J(H-3'-H-4)= 0.5; ^4J(H-2, H-3")= 0.5 ^5J(H-1,H-3')= 4.25; ^5J(H-1, H-3")= 0.5													
2c	4.98	---	5.99	4.29 - 4.33		3.89 - 3.98		AB 3.05 3.18	4.15	1.24	5.58	3.29	7.3-7.5	300
	^2J(CH-R,AB)= 15.9; ^3J(CH$_3$-CH$_2$)= 7.15; additional couplings in the AB-system of CH-R: 1.25, 1, < 0.5													
2d	4.57	---	AB 1.98 of 2.31 ABX	4.12 - 4.36		3.80	3.87 AB	AB 2.53 2.68	4.2	1.28	5.60	3.40	7.3-7.6	200
	^2J(H-3$_A$,H-3$_B$)= 12.2; ^2J(H-6$_A$,H-6$_B$)= 10.1; ^2J(CH-R,AB)= 16.75; ^3J(CH$_3$-CH$_2$)= 7.0; ^3J(H-3$_A$,H-4)= 12.1 ; ^3J(H-3$_B$,H-4)= 4.0													
4	4.91	2.43 n.r.§	3.79 - 4.01 and 4.11 - 4.37 incl.H-3' and H-2$_B$					6.12	4.2	1.26	5.67	3.38	7.3-7.6	200
	^2J(H-2$_A$,H-2$_B$)=14.8; ^3J(H-2$_A$,H-1)= 3.4; ^3J(H-2$_B$, H-1)= 0.8; ^4J(H-2$_A$,H-3')= 2.0; ^4J(H-2$_A$,H-4)= 0.8; ^3J(CH$_2$-CH$_3$)= 7.0													
5	5.80	---	AB 2.49 of 2.71 ABX	4.19 X of ABX	3.07 - 4.01			6.64	4.08	1.28	5.56	3.40	7.3-7.6	200
	^2J(H-3$_A$,H-3$_B$)= 12.0; ^3J(H-3$_4$,H-4)= 4.2; ^3J(H-3$_B$,H-4)= 12.2; ^4J(H-1,H-3$_A$)= 1.7; ^4J(H-1,H-2')= 0.5; ^3J(CH$_2$-CH$_3$)=7													
6	6.78 AB 6.69		---	3.94 - 3.97		3.37	3.46 AB	5.83	3.68	1.29	5.68	---	7.3-7.6	200
	^3J(H-1,H-2)= 6.5; ^2J(H-6$_A$,H-6$_B$)= 9.0; ^3J(H-5, H-6$_A$)= 1.5; ^3J(H-5, H-6$_B$)= 0.2; ^4J(H-2,H-3')= 2.1; ^5J(H-1,H-3')= 1,													

a CH- or CH$_2$-branching, side-chain; b ester, side-chain; c benzylidene C-H; d B$_o$, field strength in MHz

§ n.r. stands for not resolved; indices A and B indicate geminal protons in the corresponding carbohydrate-ring, whereas superscripts (' or ") are reserved for protons in a side chain

^{13}C-NMR-spectroscopic data[+]

No	C-1	C-2	C-3	C-4	C-5	C-6	C-H[a]	OMe	C-3'[c]	-CO-[b]	-CH$_2$[b]	-CH$_3$[b]	aromat
1	100.8	46.6	187.8	83.3	65.2	69.6	102.2	55.1	---	---	---	---	126.6, 128.4, 129.5, 137.8
1c	98.9	126.6	117.5	79.9	60.6	69.8	102.2	55.1	39.4	168.0	65.0	14.0	126.6, 128.4, 129.3, 137.8
2	100.8	187.1	42.9	77.3	64.3	69.2	101.7	55.8	---	---	---	---	125.3, 126.4, 128.6, 137.7
2d	101.4	72.5	41.6	75.8	64.7	69.5	102.0	55.2	36.4	172.7	61.0	14.3	126.4, 128.5, 129.3, 137.5
2c	95.3	119.4[§]	119.0[§]	78.7	64.7	69.5	102.0	55.5	36.3	165.9	60.6	14.3	126.4, 128.6, 129.4, 138.5
4	99.7	34.0	150.0	79.7	60.2	69.9	102.0	55.2	113.4	175.2	66.0	14.5	126.6, 128.4, 129.5, 138.1
5	95.2	150.5	36.2	78.3	64.7	69.5	102.0	55.4	118.9	165.1	60.6	14.3	126.4, 128.5, 129.3, 137.6
6	149.6	101.5	144.9	78.7	60.2	71.1	102.0	---	107.4	169.1	68.8	14.5	126.6, 128.6, 129.6, 137.8
7	161.5	106.4	188.3	77.6	68.0	73.2	102.4	---	---	---	---	---	126.6, 128.4, 129.2, 138.0

No	C-1	C-2	C-3	C-4	C-5	C-6	C$_i$[d]	CH$_3$/CH$_3$[d]	CH$_n$[c]	-CO-[b]	-CH$_2$[b]	-CH$_3$[b]
3	107.7	85.4	85.0	79.6	207.7	70.8	113.3	26.6/27.3				
3c	107.2	87.6[§]	84.4[§]	80.5	155.6	72.2	112.3	27.0/27.7	116.0	164.9	60.9	14.3
3d	107.1	85.8	84.6	84.1	157.2	71.9	112.5	26.6/27.3	116.8	165.8	60.6	14.3

a benzylidene C-H b ester, side-chain c -CH- or -CH$_2$-branching, side chain d of isopropylidene
§ assignment may be reversed + data for 1a, 2a and 3a have previously been reported[7]

TABLE 6

elemental analysis

No	Anal. Calcd for	C	H	Found C	Found H
1c	$C_{18}H_{22}O_6$ (334.37)	64.66	6.63	64.70	6.72
2c	$C_{18}H_{22}O_6$ (334.37)	64.66	6.63	64.72	6.69
2d	$C_{18}H_{24}O_7$ (352.39)	61.35	6.86	61.38	6.91
3c	$C_{13}H_{18}O_6$ (270.28)	57.77	6.71	57.81	6.81
3d	$C_{13}H_{18}O_6$ (270.28)	57.77	6.71	57.80	6.85
4	$C_{18}H_{22}O_6$ (334.37)	64.66	6.63	64.67	6.68
5	$C_{18}H_{22}O_6$ (334.37)	64.66	6.63	64.68	6.67
6	$C_{17}H_{18}O_5$ (302.33)	67.54	6.00	67.56	6.10

TABLE 7

^{1}H-NMR-spectroscopic data

No	H-1	H-2	H-3	H-4	H-5'[c]	H-6^c_A	H-6_B	$-CH_3^a$	CH_3^b	CH_2^b
3c	5.92	4.32	3.98	-4.35	5.89	3.98	-4.35	1.34/1.52	1.29	4.23
3d	5.95	4.72	4.41	5.06	6.07	4.98	4.72	1.18/1.46	1.22	4.14

No	^3J(H-1,H-2)	^3J(H-2,H-3)	^3J(H-3,H-4)	^2J(H-6_A,H-6_B)	^4J(H-5',H-$6_{A,B}$)[d]
3c	4.0	0.2			
3d	3.7	0.2	3.1	17.5	2.8

a of 1,2-O-isopropylidene
b of ester
c indices A and B indicate geminal protons at C-6, whereas superscript ' is reserved for the olefinic proton in the C-5 branching
d field strength B_o = 200 MHz

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