Chemistry of Natural Compounds and Bioorganic Chemistry

Stereoselective synthesis of 2-deoxy-α-D-*arabino*-hexopyranosides of triterpene alcohols

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2-Deoxy-2-iodo-α-D-mannopyranosides of triterpene alcohols of the oleanane series were synthesized in *ca.* 60% yields by glycosylation with readily accessible D-glucal triacetate in the presence of *N*-iodosuccinimide as the promotor. Their deiodination by catalytic hydrogenation followed by deacetylation yielded 2-deoxy-α-D-*arabino*-hexopyranosides of glycyrrhetic acid derivatives and allobetulin.

Key words: triterpene alcohols, 3,4,6-tri-*O*-acetyl-D-glucal, electrophilic glycosylation; *N*-iodosuccinimide; triterpene 2-deoxy-2-iodo-α-D-mannopyranosides and 2-deoxy-α-D-*arabino*-hexopyranosides.

Triterpene glycosides are found in many plants of various species and in marine invertebrates. It is known that natural triterpene glycosides possess diverse biological activities (antiinflammatory, antitumor, hemolytic, fungicidal, antiviral, *etc.*).[1,2] Recently, interest in the synthesis of compounds of this class that mimic different natural analogs, in particular, glycosides of medicinal plants (licorice, ginseng, *etc.*) has risen substantially.[3–7]

The most widespread methods for glycosylation of complex triterpene alcohols are the Koenigs—Knorr reaction and its modifications, which usually afford mixtures of α- and β-glycosides[3–7] and do not ensure satisfactory yields of the target products. At present, glycosylation with glycals as the glycosyl donors is a promising and intensely developed method for the stereoselective synthesis of 2-deoxyglycosides.[8–11] 2-Deoxyglycosides are common structural units of numerous biologically active compounds (cardiac glycosides, antibiotics, deoxyribonucleotides, *etc.*). The first synthesis of triterpene 2-deoxyglycosides has been described in one of our publications.[12]

In the present work, the synthesis of 2-deoxy-α-D-glycopyranosides of triterpene acohols of the oleanane series (Scheme 1) by electrophilic glycosylation of 3β-alcohols **2a—c** using readily available 3,4,6-tri-*O*-acetyl-D-glucal (**1**)[13] in the presence of *N*-iodosuccinimide (NIS)[14] as the promotor is described.

We used biologically active triterpenoids from the extract of roots of naked licorice (*Glycyrrhiza glabra*) and Ural licorice (*Glycyrrhiza uralensis*), 18β-glycyrrhetic acid and its 11-deoxo-analog in the form of methyl esters **2a** and **2b**,[15–17] and allobetulin **2c** obtained from

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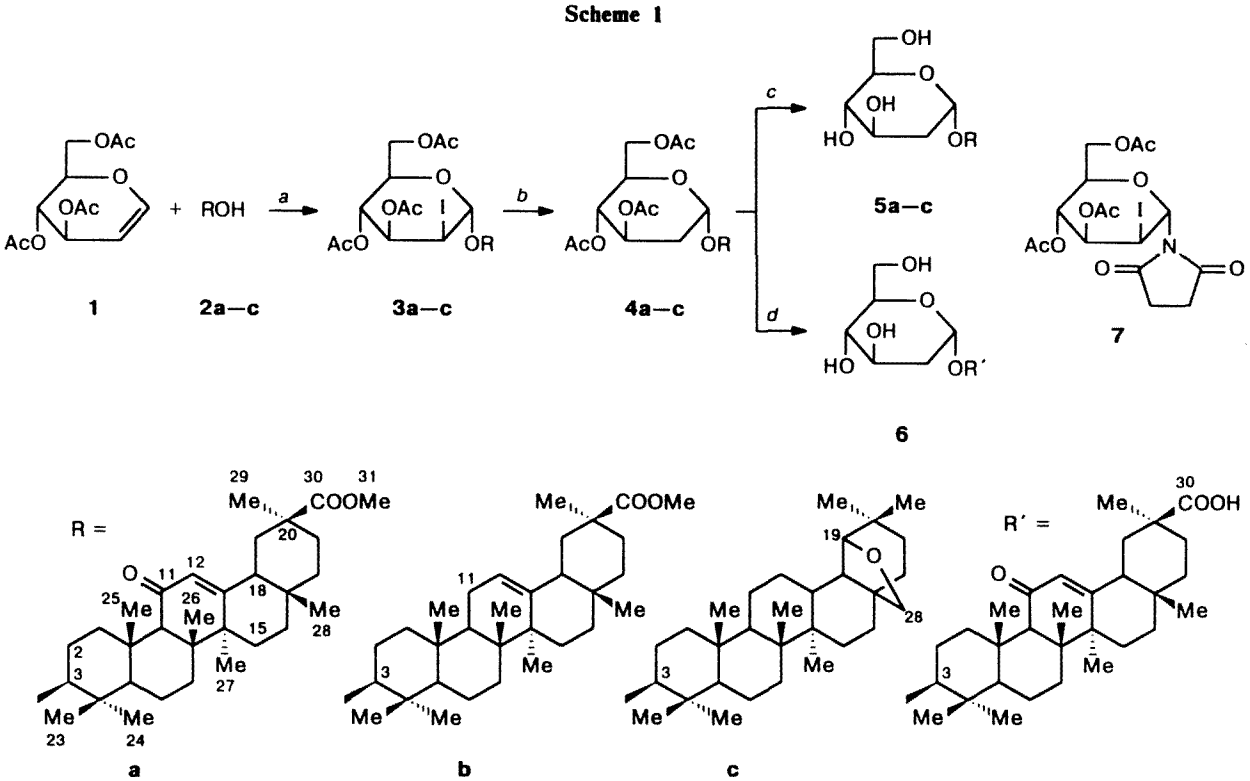
Scheme 1



Reagents and conditions: *a*. NIS, CH_2Cl_2—MeCN, molecular sieves 4 Å; *b*. 10% Pd/C, H_2; *c*. 5% KOH—MeOH; *d*. 5% KOH/Et_2O—H_2O (1 : 1).

betulin, one of the major triterpenoids from the extract of birch bark (*Betula pendula*)[18] as the alcoholic components.

Glycosylation was carried out in the dark in a 1 : 1 CH_2Cl_2—MeCN solvent system using equmolar amounts of tri-*O*-acetyl-D-glucal **1** and alcohols **2a—c** (see Scheme 1) and a slight excess of NIS in the absence of moisture at ambient temperature. The reaction proceeds stereoselectively to afford 2-deoxy-2-iodo-α-D-mannopyranosides **3a—c** in yields of 55—60%. Since the glycosylation is rather lengthy (*ca.* 70 h), the formation of a side-product, *viz.*, acylated *N*-glycoside **7**, which is apparently the adduct of glycal **1** and NIS, occurs. *N*-Glycosides like **7** have been observed previously[8] in the reaction of steroid alcohols with acetylated glycals in the presence of NIS. This side reaction decreases the yield of glycosides **3a—c**, whose isolation in the analytically pure state requires silica gel column chromatography.

Deiodination of 2-deoxy-2-iodoglycosides **3a—c** by hydrogenolysis in the presence of 10% Pd/C and triethylamine in ethanol or ethyl acetate afforded acetylated 2-deoxy-α-D-*arabino*-hexopyranosides **4a—c** in yields of 89—93% without any changes in the aglycone.

Mild deacetylation of 2-deoxyglycosides **4a—c** with 5% methanolic KOH gave 3-*O*-(2-deoxy-α-D-*arabino*-hexopyranosides) of triterpenes of the oleanane series **5a,b** (as methyl esters) and **5c** in yields of 86.3—88.4%.

Heating glycoside **4a** in 5% aqueous ethanolic KOH successfully yielded glycoside **6**, which is an analog of glycyrrhizic acid, the major component of the extract of licorice root. The yield was 69.5%. The physicochemical characteristics of glycosides **3—6** are given in Table 1.

The structures of the individual glycosides were established on the basis of ^1H and ^{13}C NMR spectra measured in the COM, JMOD, and NOE modes, and also from the data of two-dimensional NMR spectroscopy. The assignment of signals in the spectra of newly synthesized glycosides **3—6** was based on a comparison of the published data for the aglycons[18—23] and for the carbohydrate fragments[8,24] with the spectra of initial triterpenes **2a—c**.

The chemical shifts (δ) of the ^{13}C NMR signals of glycosides **3—6** are listed in Table 2. The ^{13}C NMR spectra of the aglycon parts of the glycosides synthesized are similar to those of the initial triterpenes.[19—22] In the spectra of 2-deoxy-2-iodoglycosides **3a—c**, the signals of the C(3) atoms are observed at δ 84.5—84.7. Thus, when going from genins **2a—c** to glycosides **3a—c**, the downfield shift of the C(3) signal by 5.8—6.5 ppm and the upfield shift of the C(2) signal by 3.9—4.9 ppm were observed. The anomeric carbons of the pyranose residue C(1′) in the spectra of compounds **3a—c** resonate at δ 98.3—98.5, indicating the formation of α-glycosidic bonds and the axial positions of the aglycons.[25] The

Table 1. Physicochemical properties of triterpene glycosides **3—6**

Glycoside	R_f (system)*	$[\alpha]_D^{20}$/deg (c, $CHCl_3$)	M.p. /°C	Found / Calculated (%)			Molecular formula	Molecular weight
				C	H	I		
3a	0.67 (*A*) 0.71 (*B*) 0.69 (*C*)	+82 (0.03)	204—206	58.80 58.45	7.51 7.19	14.03 14.37	$C_{43}H_{63}O_{11}I$	882.87
3b	0.68 (*A*) 0.69 (*B*)	+75 (0.06)	230—232	60.84 60.41	7.33 7.66	14.52 14.84	$C_{43}H_{65}O_{10}I$	868.89
3c	0.71 (*A*) 0.73 (*B*)	+24 (0.04)	197—199	60.34 59.99	7.30 7.19	14.56 15.09	$C_{42}H_{65}O_9I$	840.88
4a	0.63 (*A*) 0.68 (*B*)	+87 (0.04)	217—219	67.93 68.23	8.94 8.52	—	$C_{43}H_{64}O_{11}$	756.97
4b	0.65 (*A*)	+78 (0.07)	223—225	69.05 69.51	9.33 8.95	—	$C_{43}H_{66}O_{10}$	742.99
4c	0.68 (*A*)	+16 (0.09)	190—192	70.15 70.55	9.58 9.30	—	$C_{42}H_{66}O_9$	714.98
5a	0.29 (*A*)	+95 (0.02)	210—212	70.83 70.44	9.02 9.26	—	$C_{37}H_{58}O_8$	630.86
5b	0.31 (*A*)	+83 (0.05)	214—216	71.77 72.04	10.21 9.80	—	$C_{37}H_{60}O_7$	616.28
5c	0.34 (*A*)	+12 (0.06)	202—204	72.96 73.42	9.88 10.27	—	$C_{36}H_{60}O_6$	588.27
6	0.25 (*A*) 0.27 (*B*)	+133 (0.12)	198—200	70.42 70.09	8.84 9.25	—	$C_{36}H_{56}O_8$	616.84

* See Experimental.

α-configuration of the glycosidic bonds in compounds **3a—c** is also confirmed by the signals of the anomeric protons at δ 5.2—5.3 (Table 3), which appear as doublets ($J_{1',2'}$ = 1.0 to 1.1 Hz) (Table 4).

The low coupling value suggests that the configuration of the H(1′) and H(2′) protons is diequatorial, *i.e.*, the aglycons and the I atoms in the 2-deoxy-2-iodoglycosides are in a 1,2-*trans*-diaxial orientation. The chemical shifts of the proton signals of the pyranose residues of glycosides **3a—c** and the mutual arrangement of the protons indicate that the $^4C_1$(D)-conformation of acylated 2-deoxy-2-iodoglycosides is preferable.

The assignment of the signals of the C and H atoms in the NMR spectra of glycoside **3a** was based on the data of homonuclear and heteronuclear two-dimensional spectroscopy (Figs. 1 and 2). For example, in the two-dimensional $^1H—^1H$ COSY NMR spectrum (see Fig. 1), there is no weak coupling between H(1′) and

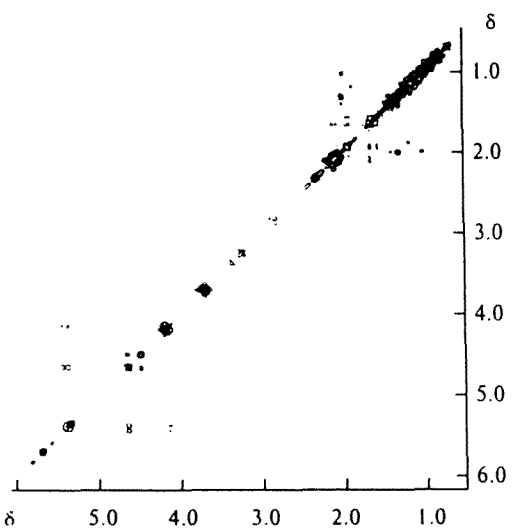


Fig. 1. Two-dimensional $^1H—^1H$ COSY NMR spectrum of glycoside **3a**.

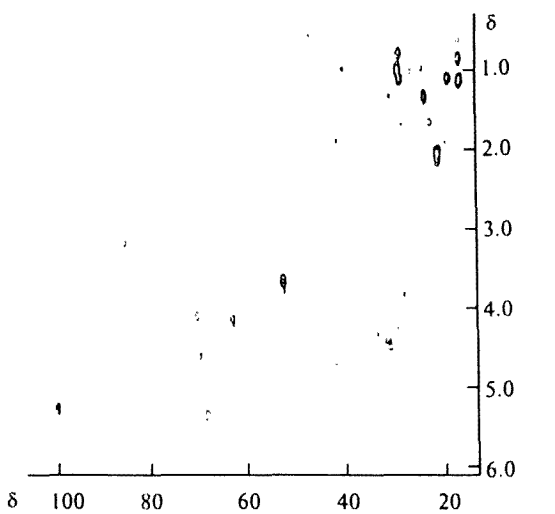


Fig. 2. Two-dimensional $^{13}C—^1H$ CORR NMR spectrum of glycoside **3a**.

Table 2. ^{13}C NMR spectral data for glycosides **3—6**

Atom	δ (in $CDCl_3$)									
	3a	**3b**	**3c**	**4a**	**4b**	**4c**	**5a**	**5b**	**5c**	**6***
C(1)	38.9	38.5	38.7	38.7	38.5	38.8	38.7	38.4	38.6	38.8
C(2)	22.4	22.3	22.4	21.8	21.9	22.1	21.7	21.8	22.0	21.3
C(3)	84.5	84.7	84.5	82.8	83.0	83.8	81.4	82.0	82.0	81.7
C(4)	38.7	38.5	38.5	38.7	38.5	38.8	38.7	38.4	38.6	38.8
C(5)	55.4	55.5	55.7	55.4	55.7	56.0	55.3	55.5	55.9	55.7
C(6)	17.5	18.4	18.2	17.5	18.4	18.4	17.5	18.3	18.3	17.4
C(7)	32.8	32.7	34.2	32.9	32.8	34.3	32.8	32.7	34.3	32.6
C(8)	43.8	39.8	40.7	43.3	39.9	40.8	43.3	39.8	40.8	43.9
C(9)	61.8	48.2	51.2	61.9	48.2	51.2	61.9	48.6	51.2	63.3
C(10)	37.0	36.9	37.2	37.0	36.9	37.3	37.0	36.9	37.3	37.6
C(11)	200.5	23.6	21.1	200.3	23.5	21.1	200.5	23.5	21.1	200.9
C(12)	128.6	122.5	26.2	128.6	122.6	26.4	128.6	122.5	26.4	128.8
C(13)	169.2	144.5	36.7	169.3	144.5	36.9	169.6	144.5	36.9	171.3
C(14)	45.5	41.5	41.4	45.5	41.9	41.6	45.5	41.5	41.6	46.1
C(15)	26.5	26.1	26.4	26.5	26.2	26.5	26.5	27.0	26.5	26.9
C(16)	26.5	26.1	26.4	26.5	26.2	26.5	26.5	27.0	26.5	26.9
C(17)	32.0	32.0	40.7	32.0	32.0	40.8	31.9	32.0	40.8	31.9
C(18)	48.4	47.7	46.8	48.5	47.7	47.0	48.5	47.6	46.9	49.2
C(19)	41.1	42.9	87.9	41.2	42.9	88.0	41.1	42.9	88.0	42.1
C(20)	44.1	44.3	36.2	44.1	44.2	36.1	44.0	44.2	36.1	43.9
C(21)	31.0	31.3	32.7	31.2	31.3	32.7	30.9	31.2	32.6	29.4
C(22)	37.8	36.7	33.9	37.8	36.7	34.1	37.8	36.9	34.0	37.6
C(23)	28.4	28.2	28.2	28.4	28.2	28.1	28.3	28.2	28.1	27.1
C(24)	16.5	15.5	16.5	16.5	15.6	16.4	16.5	15.6	16.4	17.2
C(25)	16.6	16.6	15.7	16.6	16.6	15.8	16.6	16.6	15.8	17.2
C(26)	18.8	16.7	16.5	18.8	16.8	16.6	18.8	16.8	16.6	18.1
C(27)	23.4	26.0	13.5	23.4	26.0	13.6	23.5	25.8	13.6	23.9
C(28)	28.6	28.6	71.2	28.6	28.6	71.4	28.6	28.7	71.4	29.1
C(29)	28.7	28.8	24.5	28.8	28.8	24.6	28.8	28.8	24.6	29.4
C(30)	177.1	177.8	28.8	177.0	177.7	28.9	177.1	177.9	28.9	180.0
C(31)	51.9	51.6		51.9	51.5		51.9	51.7		
C(1′)	98.5	98.4	98.3	93.2	93.3	93.3	93.4	93.4	93.5	94.3
C(2′)	30.9	31.0	31.0	35.7	35.8	35.8	38.2	38.1	38.4	37.8
C(3′)	69.3	69.3	69.2	69.1	69.3	69.4	72.0	71.8	71.9	71.5
C(4′)	67.9	67.7	67.7	68.4	68.4	68.4	69.3	69.3	69.4	70.1
C(5′)	69.7	69.6	69.6	69.3	69.7	69.7	72.7	72.7	73.0	73.9
C(6′)	62.4	62.4	62.4	62.5	62.6	62.2	62.3	62.3	62.2	62.5
C(3′)O<u>C</u>O	169.5	169.6	169.5	170.0	170.0	170.0				
C(4′)O<u>C</u>O	169.8	169.9	170.3	170.3	170.2	170.1				
C(6′)O<u>C</u>O	170.7	170.8	170.7	170.9	170.7	170.3				
OCO<u>C</u>H_3	20.8, 20.9, 21.1	20.8, 20.9, 21.1	20.6, 20.7, 20.8	20.8, 20.9, 21.1	20.7, 20.8, 21.0	20.8, 21.0, 21.1				

* Pyridine-d_5 was used as the solvent.

H(2′) protons, which indicate a small *J* value. The cross-peaks in the areas of 4.64, 5.39, and 4.10—4.20 ppm indicate unequivocally the presence of interactions between the H(3′), H(4′), and H(5′) protons, and the *J* values prove their axial orientation. As can be seen from the two-dimensional $^{13}C—^{1}H$ CORR NMR spectrum of glycoside **3a** (see Fig. 2), the signal of the H(1′) proton correlates directly with the C(1′) signal at δ 98.5, and the C(2′) atom (δ 30.9) has a cross-peak with the H(2′) proton at δ 4.48. On the basis of the positions of the cross-peaks in the $^{13}C—^{1}H$ CORR NMR spectrum and from the exact determination of the chemical shifts in the ^{1}H NMR spectrum, the signals of the C(3), C(3′)—C(6′) atoms were assigned unequivocally (see Table 2).

In the ^{13}C NMR spectrum (NOE mode) of glycoside **3a**, $J_{C(1'),H(1')}$ = 168 Hz, which proves the equatorial position of the proton at the C(1′) atom and the axial position of the aglycon.[24]

In the ^{13}C NMR spectra of acetylated glycosides **4a—c** (see Table 2), the signals of the anomeric carbons are at δ 93.2—93.3, and in the spectra of deacetylated compounds **5a—c** the signals of the anomeric carbons are at δ 93.4—93.5.

Table 3. ^{1}H NMR spectral data for glycosides **3** and **4**

Number of protons	Atom	δ (in $CDCl_3$)					
		3a	**3b**	**3c**	**4a**	**4b**	**4c**
1	H(3)	3.15 (dd)	3.20 (dd)	3.23 (br.s)	3.19 (dd)	3.12 (dd)	3.23 (d)
1	H(9)	2.25 (s)	—	—	2.32 (s)	—	—
1	H(12)	5.59 (s)	5.25 (s)	—	5.66 (s)	5.26 (s)	—
1	H(18)	2.77 (d)	—	—	2.82 (d)	—	—
1	H(19)	—	—	3.50 (s)	—	—	3.45 (s)
2	H(28)	—	—	3.42, 3.76 (both d)	—	—	3.36, 3.77 (both d)
3	H(31)	3.64 (s)	3.63 (s)	—	3.68 (s)	3.59 (s)	—
21	H(23), H(24), H(25), H(26), H(27), H(28), H(29)	0.73, 0.79, 0.94, 1.05, 1.07, 1.22 (all s)	0.75, 0.82, 0.94, 1.10 (all s)	0.79, 0.82, 0.86, 0.92, 0.98, 1.01 (all s)	0.80, 0.85, 1.01, 1.12, 1.14, 1.35 (all s)	0.71, 0.76, 0.88, 0.91, 0.94, 1.05, 1.40 (all s)	0.72, 0.79, 0.84, 0.86, 0.91 (all s)
Triterpene (CH_2, CH)		1.10—1.95 (m)	1.10—2.00 (m)	1.00—2.00 (m)	1.20—1.95 (m)	1.20—2.00 (m)	0.95—1.95 (m)
1	H(1′)	5.33 (d)	5.31 (d)	5.30 (d)	5.16 (br.s)	5.12 (d)	5.08 (br.s)
1	H(2′)	4.48 (dd)	4.47 (dd)	4.47 (dd)	—	—	—
2	H(2′)	—	—	—	1.80—2.25 (m)	1.60—2.15 (m)	1.20—2.00 (m)
1	H(3′)	4.64 (dd)	4.61 (dd)	4.62 (dd)	5.22—5.38 (m)	5.22—5.31 (m)	5.17—5.29 (m)
1	H(4′)	5.39 (t)	5.37 (t)	5.35 (t)	4.99 (t)	4.92 (t)	4.92 (t)
1	H(5′)	4.10—4.20 (m)	4.15—4.25 (m)	4.17—4.28 (m)	4.26 (dd)	4.21 (dd)	4.18 (dd)
2	H(6′)	4.10—4.20 (m)	4.15—4.25 (m)	4.17—4.28 (m)	4.00—4.10 (m)	3.98—4.06 (m)	3.95—4.10 (m)
3	OAc	1.99, 2.02, 2.03 (all s)	2.05, 2.06, 2.09 (all s)	2.03, 2.05, 2.07 (all s)	2.01, 2.03, 2.08 (all s)	1.94, 1.98, 2.02 (all s)	1.94, 1.98, 2.02 (all s)

Table 4. Coupling constants (J/Hz) in the ^{1}H NMR spectra of glycosides **3** and **4**

Coupling constant	**3a**	**3b**	**3c**	**4a**	**4b**	**4c**
$J_{3,2(eq)}$	4.6	4.6	—	4.7	3.7	7.5
$J_{3,2(ax)}$	11.1	11.1	—	11.7	11.5	7.5
$J_{18,19}$	13.7	—	—	13.8	—	—
$J_{28,17}$	—	—	7.9	—	—	7.6
$J_{1',2'(eq)}$	1.1	1.0	1.0	—	1.4	—
$J_{2'(eq),3'}$	4.2	4.1	3.9	—	—	—
$J_{3',4'}$	9.5	9.4	9.3	9.7	9.8	9.5
$J_{4',5'}$	9.5	9.4	9.3	9.7	9.8	9.5
$J_{5',6'}$	—	—	—	6.0	6.1	6.9

In the spectra of 2-deoxyglycosides **4a—c** (see Table 3), anomeric proton signals H(1′) are also observed in low field at δ 5.08, 5.12, and 5.16 as a doublet (J = 1.4 Hz) (**4b**) or as broadened singlets (**4a,c**). The signals of the H(2′) and H(3′) protons are located at δ 1.60—2.25 and 5.17—5.38 (multiplets), respectively. Since the signals of the H(4′) protons at δ 4.92 and 4.99 manifest themselves as triplets with $J_{3',4'} = J_{4',5'} = 9.5$ to 9.8 Hz, the H(3′), H(4′), and H(5′) protons are axial. The mutual arrangement of the H(1′)—H(5′) protons also confirms the $^4C_1$(D) chair conformation of 2-deoxyglycosides **4a—c**.

The signals of the C(2′) atoms in the NMR spectra of acylated 2-deoxy-2-iodoglycosides **3a—c** are observed at *ca.* 31 ppm (see Table 2). When going from compounds **3a—c** to 2-deoxyglycosides **4a—c** and deacetylated derivatives **5a—c**, the δ values for C(2′) undergo characteristic downfield shifts by 4.8 and 7.1—7.4 ppm, respectively.

Therefore, the glycosylation of triterpene alcohols of the oleanane series with tri-*O*-acetyl-D-glucal in the presence of *N*-iodosuccinimide as the activator occurs stereoselectively to form 1,2-*trans*-diaxial 2-deoxy-2-iodo-α-D-mannopyranosides. Deiodination of the latter by hydrogenolysis and mild deacetylation affords the target 2-deoxy-α-D-*arabino*-hexopyranoside derivatives of glycyrrhetic acid and allobetulin in high yields.

Experimental

The IR spectra were recorded with a Specord M80 spectrometer for suspensions in nujol. The absorption spectra were recorded with a Specord UV M400 spectrophotometer in methanol. The ^{13}C and ^{1}H NMR spectra were recorded with a Bruker AM-300 instrument (75.5 and 300 MHz, respectively). $CDCl_3$ and pyridine-d_5 were used as solvents, and $SiMe_4$ was used as the internal standard.

TLC was carried out on Silufol plates (Czech Republic) using the following solvent systems: dichloromethane—methanol, 10 : 1 (*A*); ethyl acetate—light petroleum, 2 : 1 (*B*); benzene—methanol, 7 : 3 (*C*).

The spots were visualized by spraying the plates with a 20% ethanolic solution of phosphotungstic acid followed by heating at 100—120 °C for 2—3 min. Column chromatography was carried out on silica gel L (40/100, 100/160 mm) (Czech Republic).

Melting points were determined on a Boetius heating stage, and specific rotations were measured with a Perkin-Elmer 241 MC polarimeter in a cell with a 1 dm path length.

Dichloromethane and acetonitrile were refluxed for 2 h over P_2O_5 and distilled twice. 4 Å molecular sieves were calcined at 160—180 °C (1—5 Torr) for 2 h. *N*-Iodosuccinimide was prepared according the known procedure;[14] the content of iodine was 55.8—56.1% (98—99% of the theoretical percentage).

Tri-*O*-acetyl-D-glucal (1) was synthesized according to the previously published procedure,[13] m.p. 53—54 °C, $[\alpha]_D^{20}$ −21° (*c* 0.08, $CHCl_3$). Literature data:[26] m.p. 51—54 °C, $[\alpha]_D^{20}$ −16° (EtOH).

Methyl 18β-glycyrrhetate (GL) (2a) was prepared as described previously[16] from β-glycyrrhizic acid (the content of the basic compound was *ca.* 95%); R_f 0.70 (system *A*), m.p. 252—254 °C, $[\alpha]_D^{20}$ +160±2° (*c* 0.01, MeOH). UV, λ_{max}/nm: 248.0 (log ε 4.0). Literature data:[15] m.p. 261.5—262.0 °C, $[\alpha]_D^{20}$ +163° ($CHCl_3$). Literature data:[27] m.p. 252—256 °C.

Methyl 11-deoxo-18β-GL (2b) was prepared as described previously[17] from methyl 18β-glycyrrhetate **2a**, R_f 0.71 (system *A*), m.p. 230—233 °C, $[\alpha]_D^{20}$ +107° (*c* 0.07, $CHCl_3$). Literature data:[28] m.p. 233—245 °C, $[\alpha]_D^{20}$ +115.4° (*c* 1.23, $CHCl_3$).

Allobetulin (2c) was synthesized according to the previously published procedure[18] from betulin (the content of the basic compound was *ca.* 70%); R_f 0.64 (system *A*), m.p. 258—260 °C, $[\alpha]_D^{20}$ +43° (*c* 0.07, EtOH). Literature data:[18] m.p. 265—266 °C.

Glycosylation of triterpene alcohols 2a—c with tri-*O*-acetyl-D-glucal in the presence of *N*-iodosuccinimide (general procedure). Calcined 4 Å molecular sieves (0.55 g) were added to a solution of 3,4,6-tri-*O*-acetyl-D-glucal (**1**) (0.55 g, 2 mmol) and an equmolar amount of triterpene alcohol (**2a—c**) in a mixture of anhydrous CH_2Cl_2 and MeCN (1 : 1, v/v) (50 mL). The mixture was cooled to 0 °C and *N*-iodosuccinimide (0.52 g, 2.3 mmol) was added with stirring in the dark. The temperature was allowed to increase to *ca.* 20 °C and the mixture was stirred for 70 h (TLC monitoring). The sieves were filtered off, the solvent was removed *in vacuo*, and the residue was dissolved in dichloromethane (50 mL). The resulting solution was washed with 10% $Na_2S_2O_3$ (2×20 mL), dried over Na_2SO_4, and evaporated to dryness. The residue was chromatographed on a column with silica gel to isolate analytically pure samples of the corresponding glycosides **3a—c**.

The physicochemical properties of the glycosides prepared are listed in Table 1, and the ^{13}C and ^{1}H NMR spectral data are given in Tables 2 and 3, respectively.

Methyl 3-*O*-[3,4,6-tri-*O*-acetyl-2-deoxy-2-iodo-α-D-mannopyranosyl]-3β-hydroxy-11-oxo-18β-olean-12-ene-30-carboxylate (3a). A crude product (1.62 g) was obtained from methyl 18β-GL **2a** (0.97 g, 2 mmol) and was chromatographed in a pentane—ethyl acetate gradient (7 : 1, 5 : 1, 3 : 1, 2 : 1, 1 : 1, v/v). Glycoside **3a** (homogeneous according to TLC) was eluted with the 3 : 1 → 2 : 1 gradient mixture. A finely crystalline, white powder was obtained in a yield of 0.98 g (55.8%). UV (MeOH), λ_{max}/nm: 248.4 (log ε 3.52).

Methyl 3-*O*-[3,4,6-tri-*O*-acetyl-2-deoxy-2-iodo-α-D-mannopyranosyl]-3β-hydroxy-18β-olean-12-ene-30-carboxylate (3b). A crude product (1.57 g) was obtained from methyl 11-deoxo-18β-GL **2b** (0.94 g, 2 mmol) and was chromatographed, eluting successively with chloroform and a chloroform—methanol gradient mixture (200 : 1, 150 : 1, 100 : 1, 50 : 1, v/v). Glycoside **3b** (homogeneous according to TLC) was eluted with the 150 : 1 → 100 : 1 gradient mixture and crystallized from dioxane. A finely crystalline, white powder was obtained in a yield of 1.03 g (59.5%).

3-*O*-[3,4,6-Tri-*O*-acetyl-2-deoxy-2-iodo-α-D-mannopyranosyl]-19β,28-epoxy-18α-olean-3β-ol (3c). A crude product (1.29 g) was obtained from allobetulin **2c** (0.89 g, 2 mmol) and was chromatographed as described above. After recrystallization from ethanol, a finely crystalline, white powder was obtained in a yield of 0.94 g (56.0%).

Synthesis of acetylated 2-deoxy-α-D-glycosides 4a—c (general procedure). Several drops of triethylamine were added to a solution of glycoside **3a—c** (0.5—1.0 g, 0.6—1.1 mmol) in methanol, ethanol, or ethyl acetate (15—30 mL), and the reaction mixture was hydrogenated for 6—8 days (p = 1 atm) in the presence of 10% Pd/C (0.5—1.0 g). The catalyst was filtered off, the solvent was removed *in vacuo*, and the residue was recrystallized to yield analytically pure samples of glycosides **4a—c**.

Methyl 3-*O*-[3,4,6-tri-*O*-acetyl-2-deoxy-α-D-*arabino*-hexopyranosyl]-3β-hydroxy-11-oxo-18β-olean-12-ene-30-carboxylate (4a). A solution of glycoside **3a** (1.0 g, 1.13 mmol) in methanol (30 mL) was hydrogenated for 8 days. After recrystallization from an ethyl acetate—pentane mixture, glycoside **4a** (0.8 g, 93%) was obtained as a white powder. UV (MeOH), λ_{max}/nm: 248.6 (log ε 3.62). IR, ν/cm^{-1}: 1760—1750 (OAc); 1730—1720 (COOMe); 1660 (C(11)=O); 1270 (C—O—C).

Methyl 3-*O*-[3,4,6-tri-*O*-acetyl-2-deoxy-α-D-*arabino*-hexopyranosyl]-3β-hydroxy-18β-olean-12-ene-30-carboxylate (4b). A solution of glycoside **3b** (0.85 g, 0.98 mmol) in ethyl acetate (30 mL) was hydrogenated for 7 days. After recrystallization from dioxane, glycoside **4b** (0.67 g, 92.5%) was obtained as a white powder. IR, ν/cm^{-1}: 1760—1750 (OAc); 1730—1720 (COOMe); 1260 (C—O—C).

3-*O*-[3,4,6-Tri-*O*-acetyl-2-deoxy-α-D-*arabino*-hexopyranosyl]-19β,28-epoxy-18α-olean-3β-ol (4c). A solution of glycoside **3c** (0.5 g, 0.59 mmol) in ethanol (15 mL) was hydrogenated for 6 days. After recrystallization from ethanol, glycoside **4c** (0.38 g, 89.0%) was obtained as a yellow powder. IR, ν/cm^{-1}: 1760—1750 (OAc); 1270 (C—O—C).

Synthesis of 2-deoxy-α-D-glycosides 5a—c (general procedure). 5% Methanolic KOH was added to a solution of acetates of glycosides **4a—c** in methanol, and the mixture was stirred at *ca.* 20 °C for 4 h (monitored by TLC). The mixture was treated with a KU-2-8 cation exchange resin (H^+-form), the resin was filtered off, the filtrate was diluted with cold water (30 mL), and the product was extracted with CH_2Cl_2 (3×15 mL). The combined extracts were dried with Na_2SO_4 and concentrated to dryness *in vacuo*. The products were purified by recrystallization.

Methyl 3-*O*-[2-deoxy-α-D-*arabino*-hexopyranosyl]-3β-hydroxy-11-oxo-18β-olean-12-ene-30-carboxylate (5a). A solution of glycoside **4a** (1.0 g, 1.37 mmol) in methanol (200 mL) was deacetylated by treating it with 5% methanolic KOH (30 mL). After recrystallization from an ethyl acetate—pentane mixture, glycoside **5a** (0.73 g, 87.0%) was obtained as a white powder. IR, ν/cm^{-1}: 3600—3200 (OH); 1730—1720 (COOMe); 1660 (C(11)=O); 1280 (C—O—C). UV (MeOH), λ_{max}/nm: 248.2 (log ε 3.74).

Methyl 3-*O*-[2-deoxy-α-D-*arabino*-hexopyranosyl]-3β-hydroxy-18β-olean-12-ene-30-carboxylate (5b). Glycoside **4b** (1.2 g, 1.6 mmol) was deacetylated analogously. After recrystallization from dioxane, glycoside **5b** (0.75 g, 88.4%) was obtained as a white powder. IR, ν/cm^{-1}: 3600—3200 (OH); 1730—1720 (COOMe); 1270 (C—O—C).

3-*O*-[2-Deoxy-α-D-*arabino*-hexopyranosyl]-19β,28-epoxy-18α-olean-3β-ol (5c). A solution of glycoside **4c** (0.25 g, 0.35 mmol) in methanol (50 mL) was deacetylated by treating it with 5% methanolic KOH (8 mL). After recrystallization from ethanol, glycoside **5c** (0.17 g, 86.3%) was obtained as a creamy powder. IR, ν/cm^{-1}: 3600—3200 (OH); 1270 (C—O—C).

3-*O*-[2-Deoxy-α-D-*arabino*-hexopyranosyl]-3β-hydroxy-11-oxo-18β-olean-12-ene-30-carboxylic acid (6). A solution of glycoside **5a** (0.38 g, 0.5 mmol) in a 5% solution of KOH in aqueous ethanol (1 : 1, v/v, 13 mL) was kept at *ca.* 20 °C for 10 h and then refluxed for 2 h. The mixture was diluted with water (5 mL), treated with a KU-2-8 cation exchange resin (H^+-form), and evaporated to dryness. The residue was chromatographed on a column with silica gel, eluting with a chloroform—methanol gradient mixture (200 : 1, 150 : 1, 100 : 1, 50 : 1, 25 : 1, v/v). Glycoside **6** (homogeneous according to TLC) was eluted with a 50 : 1 → 25 : 1 mixture. After crystallization from a chloroform—methanol mixture glycoside **6** was obtained as a white powder (0.21 g, 69.5%). UV (MeOH), λ_{max}/nm: 248.4 (log ε 3.89). IR, ν/cm^{-1}: 3600—3200 (OH); 1710—1700 (COOH); 1650 (C(11)=O).

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