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Synthesis and Oxidation of Thioglicosides Underlain by Neomenthanethiol, D-Glucose, and D-Fructose

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Abstract—Synthesis of sulfides proceeding from neomenthanethiol, 1,2-*O*-isopropylidene-α-*D*-glucofuranose and 2,3:4,5-di-*O*-isopropylidene-β-*D*-fructopyranose was performed to get 65 and 54% yield respectively. Oxidation of the sulfides afforded diastereomeric sulfoxides in the yields from 40 to 53%, and diastereomeric excess (*de*) up to 36%. After removing the isopropylidene protection from 1-deoxy-1-[(1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexylsulfanyl]-2,3:4,5-di-*O*-isopropylidene-β-*D*-fructopyranose a water-soluble sulfide was obtained.

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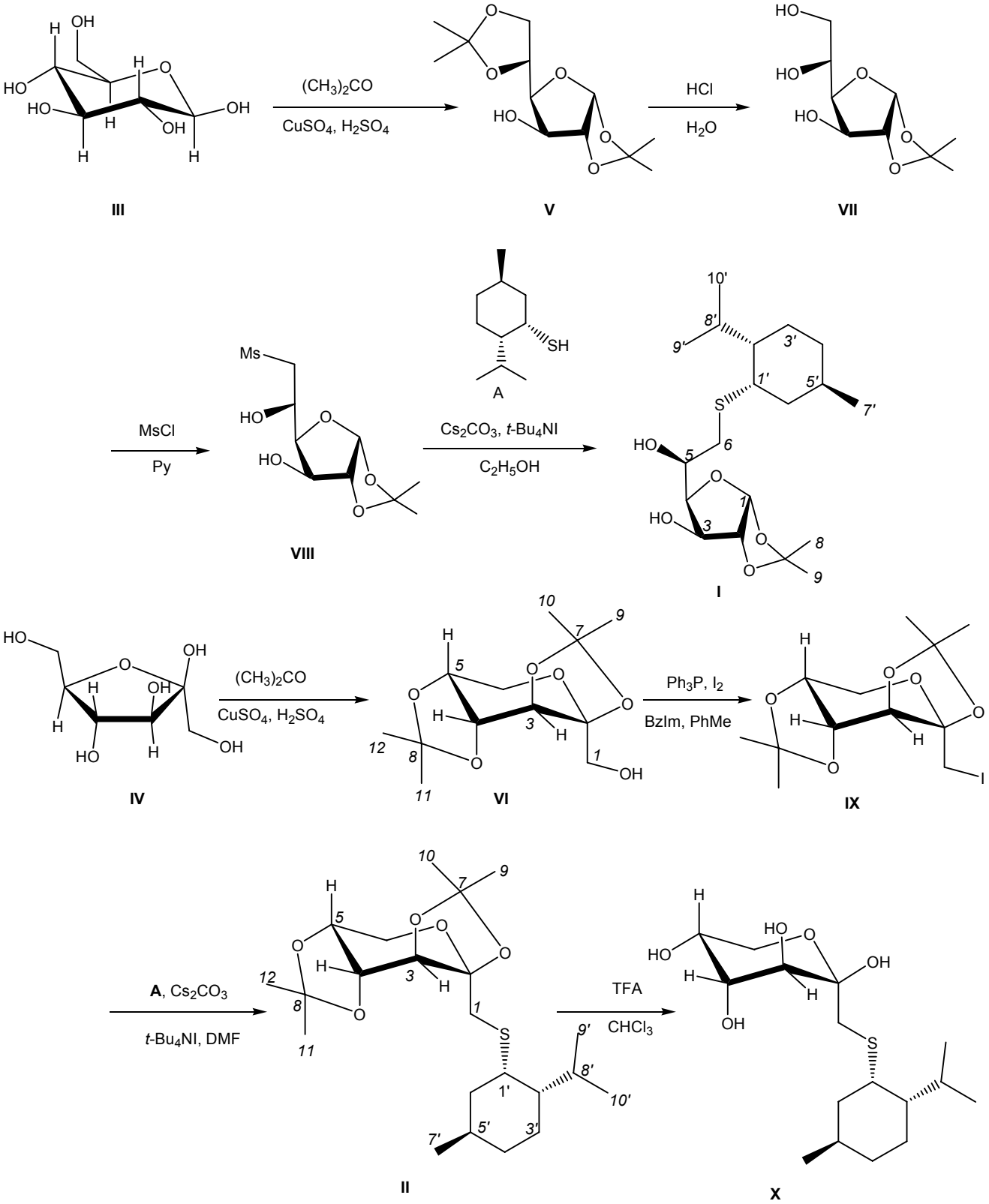
Carbohydrates owing to their special structure are the main energy source for cells of living bodies. The change in the structure of naturally occurring monosaccharides by replacing one or several hydroxy groups with other functional groups results in enhancement or in removal of their biologic activity. The replacement of one or several oxygen fragments of a monosaccharide with sulfur-containing groups is an important task for the medicinal chemistry since the synthetic thioglicosides possess a wide range of biologic action, e.g., the ability to inhibit insulin production [1], to exhibit antithrombotic [2, 3], anticancer, and antiviral action [4, 5].

In most cases the naturally occurring monosaccharides are well soluble in water environment. The introduction into the monosaccharide structure of a biologically active lipophilic fragment, for instance, terpene moiety, makes it possible to bring the latter into the aqueous solution on occasion of the retention of the water-solubility of the formed conjugate. No less importance has the retention of the diastereomeric purity (*de*) of new compounds since the monosaccharides are known to be capable to form easily epimeric compounds possessing different kinds of activity.

We formerly performed a synthesis of sulfides and sulfoxides proceeding from neomenthanethiol and *D*-galactose. The removal of the isopropylidene protecttion from the galactose fragment of sulfides and sulfoxides led to the formation of water-soluble compounds [6]. In this research a synthesis was carried out of new sulfides, 6-deoxy-6-[(1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexylsulfanyl]-1,2-*O*-isopropylidene-α-*D*-glucofuranose (**I**) and 1-deoxy-1-[(1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexylsulfanyl]-2,3:4,5-di-*O*-isopropylidene-*β*-*D*-fructopyranose (**II**) proceeding from naturally occurring *D*-glucose (**III**) and *D*-fructose (**IV**) through the intermediate formation of their diacetone derivatives **V** and **VI** (Scheme 1). Due to thermodynamic reasons the formation of glucose diacetonide (**V**) is accompanied with the contruction of the initial pyranose ring of the monosaccharide into the furanose one whereas the fructose, in contrast, at introducing the diacetonide protection forms fructopyranose diacetonide (**VI**) [7, 8]. The yields of diisopropylidene derivatives **V** and **VI** reached 77 and 90% respectively.

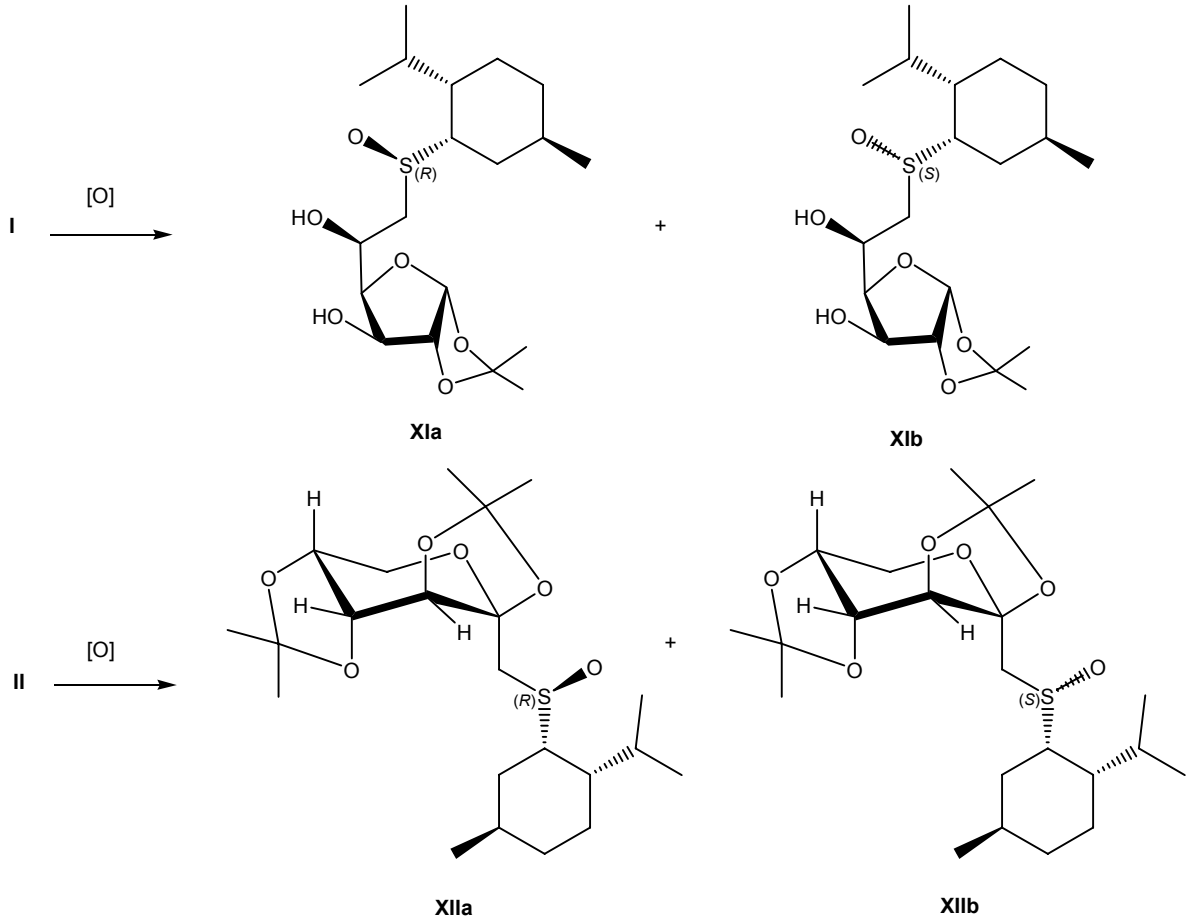
The hydroxy group at the atom C^3 in compound **V** due to the spatial hindrance does not enter in the nucleophilic substitution S_N2 and is not worth for the selective preparation of sulfides. However the action of equimolar quantity of hydrochloric acid led to the selective formation in 95% yield of 1,2-*O*-isopropylidene-α-*D*-glucofuranose (**VII**), which was

Scheme 1.



Ms is methanesulfonate, BzIm is benzimidazole, Py is pyridine.

Scheme 2.



converted into a reactive mesylate **VIII** in order to obtain sulfide **I**. We failed to prepare the corresponding mesylate from fructose diacetonide (**VI**) containing a free primary OH group at the atom C^1, therefore the synthesis of sulfide **II** was carried out via iodide **IX**. The preparative yields of sulfides **I** and **II** with accounting for the losses in all stages of the synthesis attained 65 and 54% respectively.

The structure of sulfides **I** and **II** was proved by NMR and IR spectra, the composition was confirmed by elemental analyses. ^{1}H and ^{13}C NMR spectra contained the signals of neomenthyl and monoisopropylidene-substituted glucofuranose fragments in sulfide **I** and of diisopropylidene-substituted fructopyranose moiety in sulfide **II**. In the ^{1}H NMR spectrum of sulfide **I** two characteristic doublet signals

Results of oxidation of sulfides **I** and **II**

Oxidant	Oxidation of sulfide **I**			Oxidation of sulfide **II**		
	yield, %	*de*, %	prevailing sulfoxide	yield, %	*d.e.*, %	prevailing sulfoxide
m-Chloroperoxybenzoic acid	53	20	(*R*)-**XI**	45	36	(*R*)-**XII**
tert-Butyl hydroperoxide–$VO(acac)_2$	44	19	(*R*)-**XI**	41	12	(*S*)-**XII**
Cumyl hydroperoxide–$VO(acac)_2$	40	13	(*S*)-**XI**	50	0	–

appear at 4.57 and 6.00 ppm, J 3.6 Hz, belonging to the contiguous protons H^1 and H^2 respectively. As compared to glucose monoacetonide (**VII**) the spectrum of sulfide **I** contains only two signals of OH groups at 3.17 and 3.37 ppm. All signals of protons H^1–H^5 in the ^{1}H NMR spectra are observed as strongly narrowed doublets or unresolved multiplets (pseudosinglets) indicating the retention of the furanose ring in the sulfide and the absence of the axial-equatorial (*a*-*e*) location of protons that is characteristic of the pyranose form of monosaccharides [9]. Unlike the spectrum of sulfide **I** in the ^{1}H NMR spectrum of sulfide **II** the majority of signals of protons H^1–H^6 have large spin-spin coupling constants (up to 13.3 Hz), due apparently to the diminished torsion angles between the protons caused by the additional strain in the pyranose ring with isopropylidene groups. One of protons H^6 and the proton H^5 probably form a pseudoaxial angle resulting in the increase in $J(H^5)$ to 8 and $J(H^{6a})$ to 13 Hz.

The structures of sulfides **I** and **II** are confirmed by characteristic NOE interactions. In the NOESY spectrum of sulfide **I** cross-peaks were observed between the protons H^1 and H^2, proving the α-form of the anomeric center C^1, and on the contrary, NOE interaction of the protons H^1 and H^3 of sulfide **II** showed the β-form of the anomeric center C^2.

In the IR spectra of sulfides **I** and **II** absorption bands are present characteristic of the stretching vibrations of the O–C–O group in the region 1166 cm^{-1} and of OH group at 3439 cm^{-1} in sulfide **I**.

We succeeded to remove the protecting isopropylidene groups in sulfide **II** and obtained as a result water-soluble 1-deoxy-1-[(1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexylsulfanyl]-β-*D*-fructopyranose (**X**) in a 62% yield. In the ^{1}H NMR spectrum of sulfide **X** the signals were observed of the neomenthyl fragment, and the signals of the isopropylidene methyl groups were absent. The set of signals in the ^{1}H and ^{13}C NMR spectra proved that sulfide **X** formed in the more stable β-form virtually incapable to convert into α-form due to arising additional steric hindrances caused by the neomenthyl fragment. The IR spectrum of sulfide **X** contains new strong bands of the stretching vibrations of OH groups at 3385 cm^{-1}. The removal of the isopropylidene protection in sulfide **I** with CF_3COOH at room temperature was unsuccessful, the heating of the reaction mixture at 50°C led to complete tarring.

Sulfides **I** and **II** were oxidized to sulfoxides **XI** and **XII** with *m*-chloroperoxybenzoic acid, and also with systems *tert*-butyl hydroperoxide–vanadyl acetylacetonate[$VO(acac)_2$] and cumyl hydroperoxide–$VO(acac)_2$ (Scheme 2).

Sulfoxides **XI** and **XII** were isolated by column chromatography on silica gel and characterized by NMR and IR spectra, the composition was confirmed by elemental analyses. In the IR spectra of sulfoxides **XI** and **XII** the characteristic absorption bands of the S=O group appear in the region 1056–1076 cm^{-1}. The ^{1}H and ^{13}C NMR spectra contain signals of both neomenthyl and protected glucofuranose and fructopyranose fragments. In the ^{1}H NMR spectra of compounds **XIa** and **XIb** the doublet signals of the protons H^1 and H^2, J 3.6 Hz, were conserved showing that the carbohydrate moiety remained in the furanose form. In sulfoxides **XIIa** and **XIIb** the torsion angles between protons and the corresponding coupling constants (J 13.5 Hz) were retained like in the initial sulfide **II**.

All characteristic NOE interactions in the spectra of sulfoxides **XI** and **XII** remain the same as in initial sulfides **I** and **II** both in the neomenthyl and protected glucofuranose and fructopyranose fragments.

It was formerly discovered in [6, 10] that the change in the configuration of the *S*-chiral center of the sulfinyl group bound to the neomenthyl fragment resulted in a significant change in the chemical shift of the atom $C^{6'}$ in the ^{13}C NMR spectrum that provided a possibility to predict with a high probability the configuration of the S=O group. Sulfoxides **XIb** and **XIIb** having the signals of the $C^{6'}$ atoms in the stronger field (34.12 and 34.60 ppm) compared to atoms $C^{4'}$ (34.95 and 35.35 ppm) possess the (*S*)-configuration of the sulfinyl group, and sulfoxides **XIa** and **XIIa** whose signals of $C^{6'}$ atoms are located downfield (38.75 and 36.99 ppm) from the signals of $C^{4'}$ (35.42 and 35.59 ppm), have the (*R*)-configuration (see the table).

Oxidation of sulfides **I** and **II** with three oxidants occurred with moderate yields of sulfoxides from 40 to 53%. We used an equivalent amount of the oxidant that did not lead to complete conversion of the sulfide. At excess of oxidant the reaction mixture suffered a strong tarring and the yield of sulfoxides reduced to 20%. The change of the oxidant weakly affects the diastereoselectivity of the oxidation. For instance, at the oxidation of sulfide **I** the *de* value of the obtained sulfoxides was in the range 13–20%.

We succeeded to attain the highest diastereoselectivity at the oxidation of sulfide **II** with *m*-chloroperoxybenzoic acid (*de* 36%). In most cases the prevailing sulfoxide has the (*R*)-configuration of the sulfinyl group (see the table). We failed to remove the isopropylidene protection in the obtained sulfoxides. The treatment with trifluoroacetic acid in $CHCl_3$ led to the complete tarring of the reaction mixture.

EXPERIMENTAL

IR spectra were recorded on a Fourier spectrophotometer Shimadzu IR Prestige 21 from thin films or KBr pellets. Melting points were measured on an instrument Gallencamp-Sanyo. NMR spectra were registered on a spectrometer Bruker Avance–300 [300.17(^{1}H) and 75.48 MHz (^{13}C)], internal reference chloroform signals. Total assignment of ^{1}H and ^{13}C signals was carried out with the use of 2D homo- (^{1}H–^{1}H COSY, ^{1}H–^{1}H NOESY) and heteronuclear (^{1}H–^{13}C HSQC, ^{1}H–^{13}C HMBC) experiments. The angle of optical rotation was measured on an automated digital polarimeter P3002RS (Kruss Co). TLC was performed on Sorbfil plates, solvent systems $CHCl_3$–*i*-PrOH, petroleum ether–EtOAc in various ratios, development with solution of phosphomolybdic acid or $KMnO_4$. Elemental analysis was carried out on an automatic analyzer EA 1110 CHNS-O. All reactions were carried out using freshly distilled solvents. For the column chromatography silica gel Alfa Aesar (0.06–0.2 mm) was used and the same solvent systems which were used for TLC.

(1*S*,2*S*,5*R*)-2-Isopropyl-5-methylcyclohexanethiol (neomenthanethiol) (**A**) was obtained by procedure [11]. Yield 58%, $[\alpha]_D^{22}$ +53.2 (*c* 0.83, EtOH).

1,2:5,6-Di-*O*-isopropylidene-α-*D*-glucofuranose (**V**) was obtained by procedure [12]. Yield 77%, $[\alpha]_D^{20}$ –19.0 (*c* 0.36, H_2O) (yield 48–59%, $[\alpha]_D^{20}$ –18.5 (*c* not reported, H_2O) [12]).

2,3:4,5-Di-*O*-isopropylidene-β-*D*-fructopyranose (**VI**) was obtained by procedure [13]. Yield 85%, $[\alpha]_D^{22}$ –45.6 (*c* 0.35, acetone) (yield 90%, $[\alpha]_D^{20}$ –46.0 (*c* 0.36, acetone) [13]).

1,2-*O*-Isopropylidene-α-*D*-glucofuranose (**VII**) was obtained by procedure [14]. Yield 95%, $[\alpha]_D^{20}$ –12.0 (*c* 0.32, water) (yield 80%, $[\alpha]_D^{20}$ –11.8 (*c* not reported, H_2O) [14]).

1,2-*O*-Isopropylidene-α-*D*-glucofuranos-6-yl-methanesulfonate (VIII) was obtained by procedure [16] and was used unpurified after distilling off the solvent.

1-Deoxy-1-iodo-2,3:4,5-di-*O*-isopropylidene-β-*D*-fructopyranose (IX) was obtained by procedure [15]. Yield 64%, $[\alpha]_D^{22}$ –47.6 (*c* 0.88, $CHCl_3$).

6-Deoxy-6-[(1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexylsulfanyl]-1,2-*O*-isopropylidene-α-*D*-glucofuranose (I). In 3 mL of EtOH was dissolved at stirring under argon 1.3 mmol (0.246 g) of neomenthanethiol (**III**), 1.3 mmol (0.421 g) of cesium carbonate, and 1.3 mmol (0.478 g) of *t*-Bu_4NI. After 5 min 1 mmol (0.32 g) of mesylate **VIII** was added to the above mixture. The reaction mixture was boiled for 6 h, the solvent was removed in a vacuum, the reaction product was isolated by column chromatography on silica gel (eluent petroleum ether–EtOAc, 1 : 2). Yield 91%. White powder, mp 36°C, $[\alpha]_D^{20}$ +3.32 (*c* 0.5, acetone), R_f 0.49 (petroleum ether–EtOAc, 1 : 2). IR spectrum, cm^{-1}: 3439 (OH), 2920, 1452, 1377, 1377, 1217, 1165 (O–C–O), 1017 (C–S), 1076 (C–O), 1016, 860, 797, 636 (C–S), 540. ^{1}H NMR spectrum($CDCl_3$), δ, ppm: 0.87–0.99 m (10H, $H^{4a'}$, $Me^{7'}$, $Me^{9'}$, $Me^{10'}$), 1.07–1.21 m (1H, $H^{2'}$), 1.16–1.33 m (2H, $H^{6a'}$, $H^{5'}$), 1.35 s (3H, Me^{8}), 1.52 s (3H, Me^{9}), 1.58–1.84 m (3H, $H^{4e'}$, $H^{3a'}$, $H^{8'}$), 1.88–2.06 m (2H, $H^{6e'}$, $H^{3e'}$), 2.60–2.74 m (1H, H^{6A}), 2.94–3.05 m (1H, H^{6B}), 3.17 s (1H, OH^{1}), 3.24 s (1H, $H^{1'}$), 3.37 d (1H, OH^{2}, *J* 3.1 Hz), 3.99–4.12 m (2H, H^{3}, H^{5}), 4.41 s (1H, H^{4}), 4.57 d (1H, H^{2}, *J* 3.6 Hz), 6.00 d (1H, H^{1}, *J* 3.6 Hz). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 20.73 ($C^{9'}$), 21.04 ($C^{10'}$), 22.12 ($C^{7'}$), 25.80 ($C^{3'}$), 26.20 (C^{8}), 26.84 (C^{9}), 29.94 ($C^{5'}$, $C^{8'}$), 35.33 ($C^{4'}$), 35.74 (C^{6}), 39.96 ($C^{6'}$), 46.02 ($C^{1'}$), 48.64 ($C^{2'}$), 67.99 (C^{5}), 75.59 (C^{4}), 81.76 (C^{3}), 85.16 (C^{2}), 105.06 (C^{1}), 111.73 (C^{7}). Found, %: C 60.87; H 9.17; S 8.49. $C_{19}H_{34}O_5S$. Calculated, %: C 60.93; H 9.15; S 8.56.

1-Deoxy-1-[(1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexylsulfanyl]-2,3:4,5-di-*O*-isopropylidene-β-*D*-fructopyranose (II). In 3 mL of DMF was dissolved at stirring under argon 1.3 mmol (0.224 g) of neomenthanethiol, 1.3 mmol (0.424 g) of cesium carbonate, and 1.3 mmol (0.48 g) of *t*-Bu_4NI. After 5 min 1 mmol (0.37g) of 1-deoxy-1-iodo-2,3;4,5-di-*O*-isopropylidene-β-*D*-fructopyranose (**IX**) was added to the above mixture. The reaction mixture was boiled for 72 h. On cooling the solution was diluted with 10 mL of EtOAc and washed with water (3 × 5 mL), dried with Na_2SO_4, the solvent was removed in a vacuum, the residue was separated by column chromatography

on silica gel (eluent petroleum ether–EtOAc, 5 : 1). Yield 95%. White powder, mp 79°C, $[\alpha]_D^{20}$ +26.8 (*c* 0.39, EtOH), R_f 0.44 (petroleum ether–EtOAc, 6 : 1). IR spectrum, cm^{-1}: 2938, 2907, 1447, 1373, 1246, 1167 (O–C–O), 1156 (C–O), 991, 692 (C–S), 629. ^1H NMR spectrum ($CDCl_3$), δ, ppm: 0.81–0.90 m (1H, $H^{4a'}$), 0.88 d (3H, $Me^{7'}$, *J* 6.4 Hz), 0.92 d (3H, $Me^{10'}$, *J* 6.7 Hz), 0.99 d (3H, $Me^{9'}$, *J* 6.4 Hz), 1.04–1.30 m (3H, $H^{2'}$, $H^{6a'}$, $H^{3a'}$), 1.37 s (3H, Me^{12}), 1.48 s (3H, Me^{11}), 1.51 s (3H, Me^{9}), 1.56 s (3H, Me^{10}), 1.65–1.81 m (3H, $H^{3e'}$, $H^{4e'}$, $H^{8'}$), 1.92–2.11 m (2H, $H^{6e'}$, $H^{5'}$), 2.79 d (1H, H^{1A}, *J* 13.3 Hz), 3.14 d (1H, H^{1B}, *J* 13.3 Hz), 3.21 d (1H, $H^{1'}$, *J* 1.8 Hz), 3.79 d (1H, H^{6A}, *J* 13.0 Hz), 3.95 d.d (1H, H^{6B}, *J* 13.0, 1.8 Hz), 4.25 d (1H, H^5, *J* 8.0 Hz), 4.36 d (1H, H^3, *J* 2.6 Hz), 4.63 d.d (1H, H^4, *J* 8.0, 2.6 Hz). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 16.84 ($C^{9'}$), 16.99 ($C^{10'}$), 18.06 ($C^{7'}$), 19.97 (C^{12}), 21.62 (C^{11}), 21.62 ($C^{3'}$), 21.82 ($C^{5'}$), 22.10 (C^{9}), 22.57 (C^{10}), 25.85 ($C^{8'}$), 31.33 ($C^{4'}$), 36.49 ($C^{6'}$, C^{1}), 44.62 ($C^{1'}$), 45.10 ($C^{2'}$), 57.50 (C^{6}), 66.32 (C^{4}), 66.86 (C^{3}), 68.14 (C^{5}), 99.02 (C^{2}), 104.30 (C^{7}), 104.87 (C^{8}). Found, %:, C 64.38; H 9.58; S 7.87. $C_{22}H_{38}O_5S$. Calculated, %: C 63.73; H 9.24; S 7.73.

1-Deoxy-1-[(1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexylsulfanyl]-β-*D*-fructopyranose (X). To a solution of 1 mmol (0.416 g) of sulfide **II** in 5 mL of $CHCl_3$ was slowly added dropwise at vigorous stirring 4 mmol (0.3 mL) of CF_3COOH. After 24 h of continuous stirring the solvent was distilled off in a vacuum. The residue was separated by column chromatography on silica gel (eluent $CHCl_3$–*i*-PrOH, 5 : 1). Yield 62%. Brown viscous fluid, $[\alpha]_D^{20}$ +37.8 (*c* 0.19, EtOH), R_f 0.28 ($CHCH_3$–*i*-PrOH, 5 : 1). IR spectrum, cm^{-1}: 3385 (OH), 2949, 2920, 1674, 1144, 1086 (C–O), 723 (C–S). ^1H NMR spectrum ($CDCl_3$–DMSO-d_6), δ, ppm: 0.65–0.97 m (9H, $Me^{7'}$, $Me^{9'}$, $Me^{10'}$), 0.77–0.87 m (1H, $H^{4a'}$), 0.98–1.29 m (2H, $H^{3a'}$, $H^{6a'}$), 1.51–1.77 m (3H, $H^{3e'}$, $H^{4e'}$, $H^{8'}$), 1.86–2.05 m (1H, $H^{5'}$), 2.80–3.05 m (5H, $H^{6e'}$, H^{1}, H^{6}), 3.10–3.30 m (1H, $H^{2'}$, $H^{1'}$), 3.55–3.79 m (2H, H^3, H^4), 3.80–4.41 m (1H, H^5). ^{13}C NMR spectrum ($CDCl_3$–DMSO-d_6), δ, ppm: 20.93 ($C^{9'}$), 21.08 ($C^{10'}$), 22.19 ($C^{7'}$), 25.69 ($C^{3'}$), 26.51 ($C^{5'}$), 29.98 ($C^{8'}$), 35.29 ($C^{4'}$), 39.89 ($C^{6'}$), 40.72 (C^{1}), 41.55 (C^{6}), 29.15 ($C^{2'}$), 49.35 ($C^{1'}$), 69.58 (C^{5}), 71.17 (C^{4}), 71.25 (C^{3}), 97.08 (C^{2}). Found, %: C 54.92; H 8.58; S 9.17. $C_{16}H_{30}O_6S$. Calculated, %: C 54.83; H 8.63; S 9.15.

Oxidation of sulfides I and II. *a*. With *m*-chloroperoxybenzoic acid. To a solution of 1 mmol [0.375 g (**I**), 0.416 g (**II**)] of sulfide in 3 mL of $CHCl_3$ at 0°C under vigorous stirring was slowly added a solution of 1.2 mmol (0.295 g) of 70% *m*-chloroperoxybenzoic acid in 2 mL of $CHCl_3$. After 30 min in event of sulfide **I** and 5 days in the case of sulfide **II** the solvent was distilled off in a vacuum. The residue was separated by column chromatography on silica gel [eluent petroleum ether– EtOAc, 1 : 5 (**I**) and 1 : 1 (**II**)]. Yield of sulfoxides **XI** 53%, *de* 20%; yield of sulfoxides **XII** 45%, *de* 36%.

b. In a system *tert*-butylhydroperoxide–$VO(acac)_2$. A mixture of 1 mmol of sulfide [0.375 g (**I**), 0.416 g (**II**)] in 5 mL of $CHCl_3$ and 0.01 mmol (2.7 mg) of $VO(acac)_2$ was stirred for 5 min, and a solution of 2.5 mmol of *tert*-butylhydroperoxide in $CHCl_3$ was slowly added, the mixture was stirred for 30 min at room temperature. After distilling off the solvent the reaction products were isolated by column chromatography on silica gel [eluent petroleum ether– EtOAc, 1 : 5 (**I**) and 1 : 1 (**II**)]. Yield of sulfoxides **XI** 44%, *de* 19%; yield of sulfoxides **XII** 41%, *de* 12%.

c. In a system cumyl hydroperoxide–$VO(acac)_2$. In 5 mL of $CHCl_3$ was dissolved 1 mmol of sulfide [0.375 g (**I**), 0.416 g (**II**)] and 0.01 mmol (2.7 mg) of $VO(acac)_2$, a solution of 1.1 mmol of cumyl hydroperoxide in $CHCl_3$ was added at stirring. After 12 h in the case of sulfide **I** and 2 h in event of sulfide **II** the solvent was distilled off in a vacuum. The reaction products were isolated by column chromatography on silica gel [eluent petroleum ether–EtOAc, 1 : 5 (**I**) and 1 : 1 (**II**)]. Yield of sulfoxides **XI** 40%, *de* 13%; yield of sulfoxides **XII** 50%, *de* 0%.

6-Deoxy-6-[(*R*$_S$,1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexylsulfinyl]-1,2-*O*-isopropylidene-α-*D*-glucofuranose (XIa). White powder, mp 140°C, $[\alpha]_D^{20}$ +45.6 (*c* 0.43, acetone), R_f 0.20 (petroleum ether–EtOAc, 1 : 5). IR spectrum, cm^{-1}: 3260 (OH), 2949, 1456, 1215, 1165 (O–C–O), 1076 (S=O), 1014, 725, 613 (C–S). ^1H NMR spectrum ($CDCl_3$), δ, ppm: 0.87 d (3H, $Me^{7'}$, *J* 6.2 Hz), 0.95 d (3H, $Me^{9'}$, *J* 6.4 Hz), 0.89–0.98 m (1H, $H^{4a'}$), 1.10 d (3H, $Me^{10'}$, *J* 6.4 Hz), 1.23–1.49 m (3H, $H^{6a'}$, $H^{5'}$, $H^{2'}$), 1.35 s (3H, Me^{8}), 1.54 s (3H, Me^{9}), 1.60–1.78 m (1H, $H^{3a'}$), 1.82–2.12 m (4H, $H^{8'}$, $H^{3e'}$, $H^{4e'}$, $H^{6e'}$), 2.84 t (1H, H^{6A}, *J* 11.8 Hz), 3.23 d (1H, H^{6B}, *J* 11.5 Hz), 3.42 s (1H, $H^{1'}$), 4.07 d.d (1H, H^3 *J* 8.5, *J* 1.5 Hz), 4.29–4.47 m (1H, H^4, H^5), 4.56 d (1H, H^2, *J* 3.6 Hz), 4.86 br.s (1H, OH^1), 5.90 br.s (1H, OH^2), 5.95 d (1H, H^1, *J* 3.6 Hz). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 21.70 ($C^{10'}$), 21.83 ($C^{9'}$), 22.40 ($C^{7'}$), 25.79 ($C^{3'}$), 26.12 (C^{8}), 26.84 (C^{9}), 28.02 ($C^{5'}$), 29.84

($C^{8'}$), 35.42 ($C^{4'}$), 37.22 ($C^{6'}$), 50.08 ($C^{2'}$), 52.77 (C^{6}), 61.51 (C^{5}), 62.22 ($C^{1'}$), 73.98 (C^{4}), 83.91 (C^{3}), 85.07 (C^{2}), 105.48 (C^{1}), 111.45 (C^{7}). Found %, C 58.45; H 8.76; S 8.25. $C_{19}H_{34}O_6S$. Calculated, %: C 58.43; H 8.78; S 8.21.

6-Deoxy-6-[(S_S,1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexylsulfinyl]-1,2-*O*-isopropylidene-α-*D*-glucofuranose (XIb). White powder, mp 154°C, $[\alpha]_D^{20}$ +46.2 (*c* 0.39, acetone), R_f 0.32 (petroleum ether–EtOAc, 1 : 5). IR spectrum, cm^{-1}: 3318 (OH), 1217, 1163 (O–C–O), 1074 (S=O), 1011, 889, 795, 617 (C–S). ^1H NMR spectrum ($CDCl_3$), δ, ppm: 0.89 d (3H, $Me^{7'}$, *J* 6.4 Hz), 0.91 d (3H, $Me^{10'}$, *J* 5.1 Hz), 0.88–0.98 m (1H, $H^{4a'}$), 1.00 d (3H, $Me^{9'}$, *J* 6.4 Hz), 1.25–1.47 m (3H, $H^{6a'}$, $H^{3a'}$, $H^{2'}$), 1.35 s (3H, Me^{8}), 1.52 s (3H, Me^{9}), 1.67–1.82 m (1H, $H^{8'}$), 1.83–1.97 m (2H, $H^{3e'}$, $H^{4e'}$), 1.98–2.19 m (1H, $H^{5'}$), 2.50 d (1H, $H^{6e'}$, *J* 14.4 Hz), 2.98 d.d (1H, H^{6A} *J* 13.5, 1.5 Hz), 3.06 br.s (1H, $H^{1'}$), 3.16 d.d (1H, H^{6B}, *J* 13.1, 9.8 Hz), 3.91 br.s (1H, OH^{1}), 4.06 d.d (1H, H^{3} *J* 8.5, *J* 2.6 Hz), 4.4 d (1H, H^{4}, *J* 2.3 Hz), 4.54–4.69 m (1H, H^{2}, H^{5}), 5.02 br.s (1H, OH^{2}), 5.96 d (1H, H^{1}, *J* 3.6 Hz). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 21.21 ($C^{9'}$), 21.57 ($C^{10'}$), 22.75 ($C^{7'}$), 26.18 ($C^{3'}$), 26.18 (C^{8}), 26.86 (C^{9}), 27.80 ($C^{5'}$), 29.42 ($C^{8'}$), 34.12 ($C^{6'}$), 34.95 ($C^{4'}$), 47.63 ($C^{2'}$), 53.36 (C^{6}), 59.53 ($C^{1'}$), 67.40 (C^{5}), 74.41 (C^{4}), 83.05 (C^{3}), 85.15 (C^{2}), 105.25 (C^{1}), 111.68 (C^{7}). Found, %:, C 58.41; H 8.75; S 8.23. $C_{19}H_{34}O_6S$. Calculated, %: C 58.43; H 8.78; S 8.21.

1-Deoxy-1-[(R_S,1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexylsulfinyl]-2,3:4,5-di-*O*-isopropylidene-β-*D*-fructopyranose (XIIa). White powder, mp 139°C, $[\alpha]_D^{20}$ +87.9 (*c* 0.09, EtOH), R_f 0.45 (petroleum ether–EtOAc, 1 : 1). IR spectrum, cm^{-1}: 2943, 1166 (O–C–O), 1109 (C–O), 1452, 1056 (S=O), 756, 692 (C–S). ^1H NMR spectrum ($CDCl_3$), δ, ppm: 0.84 d (3H, $Me^{7'}$, *J* 6.4 Hz), 0.91 d (3H, $Me^{10'}$, *J* 6.7 Hz), 0.95–1.06 m (1H, $H^{4a'}$), 1.07 d (3H, $Me^{9'}$, *J* 6.4 Hz), 1.19–1.33 m (1H, $H^{6a'}$), 1.37 s (3H, Me^{12}), 1.33–1.47 m (1H, $H^{2'}$), 1.51 s (3H, Me^{11}), 1.53 s (3H, Me^{9}), 1.59 s (3H, Me^{10}), 1.68–1.83m (2H, $H^{3a'}$, $H^{5'}$), 1.84–2.01 m (3H, $H^{6e'}$, $H^{4e'}$, $H^{3e'}$), 2.15–2.30 m (1H, $H^{8'}$), 3.11 d (1H, H^{1A} *J* 13.6 Hz), 3.41 d (1H, H^{1B}, *J* 13.6 Hz), 3.43 s (1H, $H^{1'}$), 3.75 d (1H, H^{6A}, *J* 13.1 Hz), 3.98 d. d (1H, H^{6B}, *J* 13.0, 1.8 Hz), 4.24 d (1H, H^{5}, *J* 8.0 Hz), 4.58–4.75 m (1H, H^{3}, H^{4}). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 22.07 ($C^{9'}$), 22.22 ($C^{10'}$), 22.36 ($C^{7'}$), 23.92 (C^{12}), 25.28 (C^{9}), 25.72 ($C^{3'}$), 26.02 (C^{11}), 26.56 (C^{10}), 27.56 ($C^{5'}$), 28.95 ($C^{8'}$), 35.59 ($C^{4'}$), 36.99 ($C^{6'}$), 50.62 ($C^{2'}$), 61.25 ($C^{1'}$), 61.84 (C^{1}), 62.31 (C^{6}), 70.15 (C^{4}), 70.50 (C^{3}), 72.64 (C^{5}), 101.53 (C^{2}), 109.01 (C^{7}), 109.46 (C^{8}). Found, %: C 61.33; H 8.87; S 7.41. $C_{22}H_{38}O_6S$. Calculated, %: C 61.37; H 8.90; S 7.45.

1-Deoxy-1-[(S_S,1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexylsulfinyl]-2,3:4,5-di-*O*-isopropylidene-β-*D*-fructopyranose (XIIb). White powder, mp 124°C, $[\alpha]_D^{20}$ +75.4 (*c* 0.12, EtOH), R_f 0.41 (petroleum ether–EtOAc, 1 : 1). IR spectrum, cm^{-1}: 2947, 1105 (O–C–O), 1057 (S=O), 1028 (C–O), 763, 677 (C–S). ^1H NMR spectrum ($CDCl_3$), δ, ppm: 0.88 d (3H, $Me^{7'}$, *J* 6.4 Hz), 0.85–0.96 m (1H, $H^{4a'}$), 0.95 d (3H, $Me^{10'}$, *J* 6.7 Hz), 1.01 d (3H, $Me^{9'}$, *J* 6.4 Hz), 1.20–1.45 m (2H, $H^{6a'}$, $H^{2'}$), 1.38 s (3H, Me^{12}), 1.43 s (3H, Me^{11}), 1.53 s (3H, Me^{9}), 1.55 s (3H, Me^{10}), 1.59–1.72 m (1H, $H^{3a'}$), 1.75–1.92 m (2H, $H^{3e'}$, $H^{4e'}$), 1.92–2.04 m (1H, $H^{8'}$), 2.16–2.42 m (1H, $H^{5'}$), 2.51 d (1H, $H^{6e'}$, *J* 14.5 Hz), 3.05 s (1H, $H^{1'}$), 3.31 d (1H, H^{1A}, *J* 13.5 Hz), 3.38 d (1H, H^{1B}, *J* 13.5 Hz), 3.75 d (1H, H^{6A}, *J* 13.1 Hz), 3.98 d.d (1H, H^{6B}, *J* 13.1, 1.8 Hz), 4.25 d (1H, H^{5}, *J* 8.0 Hz), 4.38 d (1H, H^{3}, *J* 2.6 Hz), 4.64 d.d (1H H^{4}, *J* 7.8, 2.7 Hz). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 21.43 ($C^{9'}$), 21.51 ($C^{10'}$), 23.05 ($C^{7'}$), 24.26 ($C^{12'}$), 24.99 (C^{9}), 25.97 (C^{11}), 26.23 (C^{10}), 26.34 ($C^{3'}$), 27.67 ($C^{5'}$), 29.43 ($C^{8'}$), 34.60 ($C^{6'}$), 35.35 ($C^{4'}$), 48.32 ($C^{2'}$), 57.30 ($C^{1'}$), 61.57 (C^{1}), 62.09 (C^{6}), 70.39 (C^{4}), 70.52 (C^{3}), 73.12 (C^{5}), 101.71 (C^{2}), 108.80 (C^{7}), 109.45 (C^{8}). Found, %: C 61.33; H 8.89; S 7.42. $C_{22}H_{38}O_6S$. Calculated, %: C 61.37; H 8.90; S 7.45.

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