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Synthesis of deoxy derivatives of the glucosinolates glucotropaeolin and glucobrassicin

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Abstract

The syntheses of 3,4,6-tri-*O*-acetyl-2-deoxy-1-thio-D-*arabino*-hexopyranose, 2,4,6-tri-*O*-acetyl-3-deoxy-1-thio-β-D-*ribo*-hexopyranose, 2,3,6-tri-*O*-benzoyl-4-deoxy-1-thio-β-D-*xylo*-hexopyranose, and 2,3,4-tri-*O*-acetyl-6-deoxy-1-thio-β-D-glucopyranose are reported. These thiols were coupled with phenylacetohydroximoyl chloride or indol-3-ylacetohydroximoyl chloride, respectively. Sulfation and subsequent deprotection yielded the corresponding deoxy derivatives of glucotropaeolin and glucobrassicin, two major representatives of the glucosinolate family.

Keywords: Glucosinolates; Glucotropaeolin; Glucobrassicin; 1-Thioglucopyranose; Deoxy derivatives

1. Introduction

Oil-seed rape production is of extraordinary agricultural importance in France and Germany. Even though rape-seed contains proteins of high quality with a well-balanced composition of amino acids, the use of rape-seed meal for feeding animals is hampered by the occurrence of glucosinolates in the rape flour. Glucosinolates constitute a structurally homogeneous group of anomeric thiohydroximoyl derivatives of 1-thio-D-

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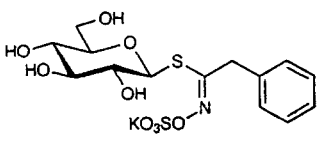

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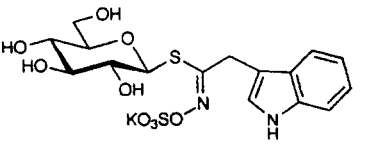

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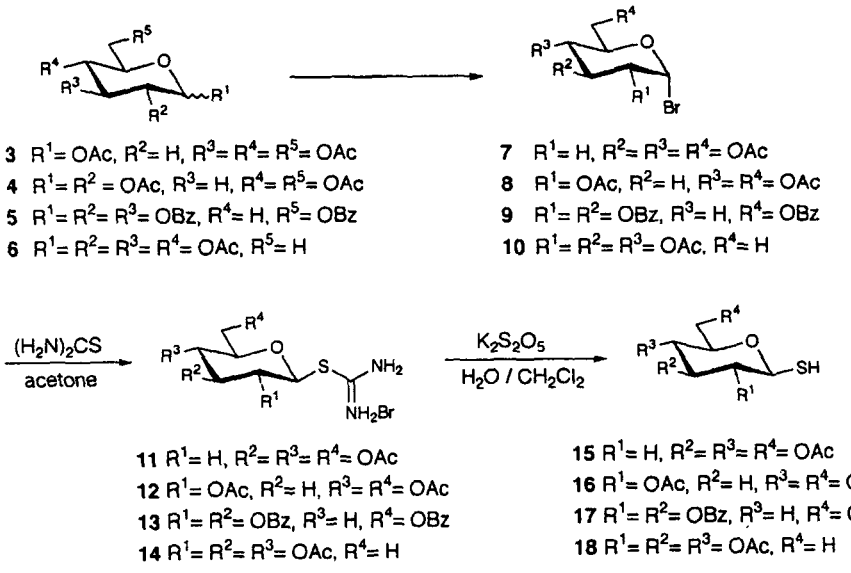
glucopyranose, which differ only in the aglycon moiety [1] (**1** and **2**). More than 100 different naturally occurring glucosinolates are known today and a number of these have been synthesized [2]. They cause distinct poisoning syndromes of higher vertebrates, namely loss of weight, hypertrophy of kidney, liver, and thyroid gland, or disturbance of reproduction [3]. These symptoms result from glucosinolates that decompose to give a variety of products including isothiocyanates, thiocyanates, nitriles, and epithiocyanoalkanes. Degradation of glucosinolates predominantly occurs enzymatically due to the action of myrosinase (thioglucoside glucohydrolase, EC 3.2.3.1) an enzyme that is found in all glucosinolate-containing plants.

For a better understanding of the natural metabolism of glucosinolates, several derivatives have been synthesized [4–7]. The synthesis of modified substrates that differ in the sugar moiety is presented here for the first time. Glucotropaeolin (**1**) is one of the two commercially available glucosinolates and was therefore chosen as the parent structure for the syntheses of its four monodeoxy derivatives. Glucobrassicin (**2**) is another important, naturally occurring glucosinolate, which seems to have a strong physiological activity [3]. To demonstrate the general applicability of our synthetic scheme, we further synthesized the 2-deoxy and 6-deoxy derivatives of glucobrassicin. The key step of the synthesis is the coupling reaction between the nitrile oxide of the aglycon and the deoxygenated derivative of 1-thio-β-D-glucopyranose (see Schemes 3 and 4). Subsequent sulfation and deprotection of the sugar moiety yields the glucosinolate. The acylated thioglycosyl compounds were prepared according to Černý et al. [8] starting from the corresponding acylated glycosyl bromide (Scheme 1) via the isothiouronium derivative and subsequent reduction with potassium metabisulfite.

2. Results and discussion

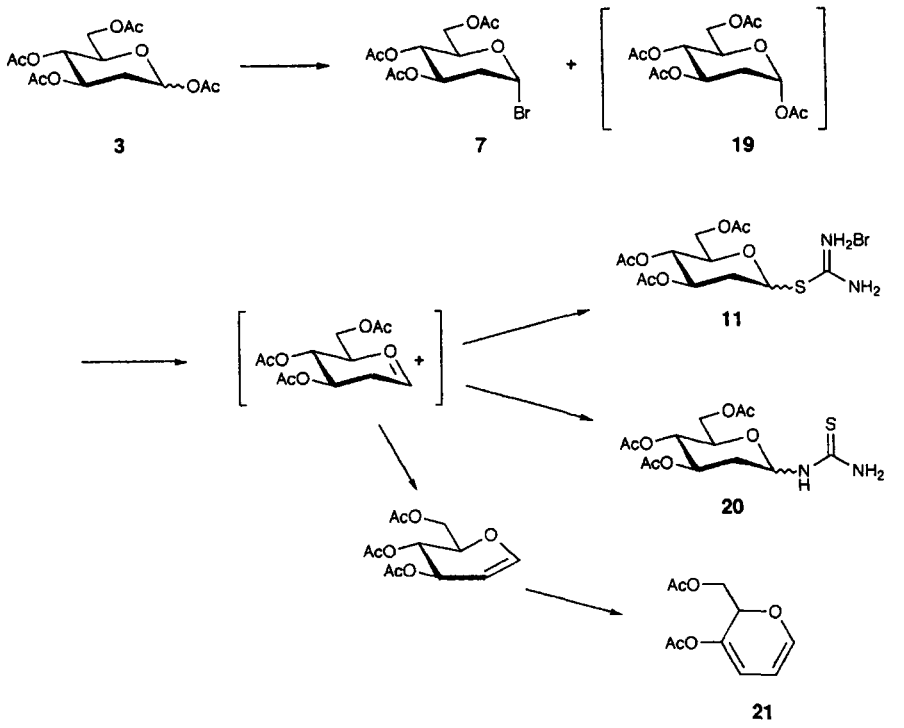
Peracetylated 2-deoxy-D-*arabino*-hexose (2-deoxyglucose) (**3**, anomeric mixture) was treated with trimethylsilyl bromide in anhydrous toluene to give exclusively the 2-deoxy α-bromide **7**. In accordance with the original procedure [9] no β-bromide could be detected by means of ^{1}H NMR spectroscopy. Because of its lability, **7** was converted into the isothiouronium salt **11** without purification employing the method of Černý et al. [8]. Since the purification of **11** was also troublesome it was used directly in the next step. By-products **19** and **21** were isolated by means of silica gel chromatography, in accordance with Fuentes et al. [10] who obtained analogous products in a comparable reaction. The presence of 1,3,4,6-tetra-*O*-acetyl-2-deoxy-α-D-*arabino*-hexopyranose (**19**)



Scheme 1.

indicates that the α-anomer was slightly less reactive in the reaction with trimethylsilyl bromide than the β-anomer. This is consistent with the theory that the α-anomer is stabilized by the anomeric effect [11–13]. A second by-product was shown to be 3-acetoxy-2-acetoxymethyl-2*H*-pyran (**21**) by means of ^{1}H NMR and MS [10]. Furthermore, a third by-product was isolated and identified as 3,4,6-tri-*O*-acetyl-2-deoxy-D-*arabino*-hexopyranosylthiourea (**20**) with the α-anomer being the major component. The occurrence of the 2*H*-pyran **21** indicates that the general reaction mechanism is predominantly of the S_N1-type (Scheme 2). The oxocarbenium ion allows the formation of compound **21** as well as the desired product **11** (anomeric mixture) and its regioisomer **20**. In those cases with 2-acyloxy functions (**8**, **9**, **10**), only the β-isothiouronium salts **12**, **13**, and **14** are formed, which indicates an S_N2-type reaction involving exclusively the very nucleophilic S-atom of thiourea. The oxocarbenium ion formed in the case of the 2-deoxy series is very reactive, hence unselective, and therefore both the S-atom and the less nucleophilic N-atom of thiourea are attacked, which leads to the formation of the by-product **20**. Compounds **20** and **21** were obtained in approximately 20% and 15% yield, respectively. To suppress the formation of these by-products a shift of the reaction mechanism towards S_N2-type would be of interest. Usually the rather polar acetone is employed as a solvent in the Černý-reaction, which favours S_N1-type reactions. Consequently toluene was checked as a solvent but no reaction occurred. Following the route outlined in Scheme 1 the isothiouronium salt was reductively transformed to give **15** (36% yield with respect to the peracetate **3**) as an anomeric mixture with an α/β ratio of 1:1 according to ^{1}H NMR spectra. Separation of the anomers by silica gel chromatography was not successful.

The other peracylated derivatives **4**, **5**, and **6** were converted into the corresponding

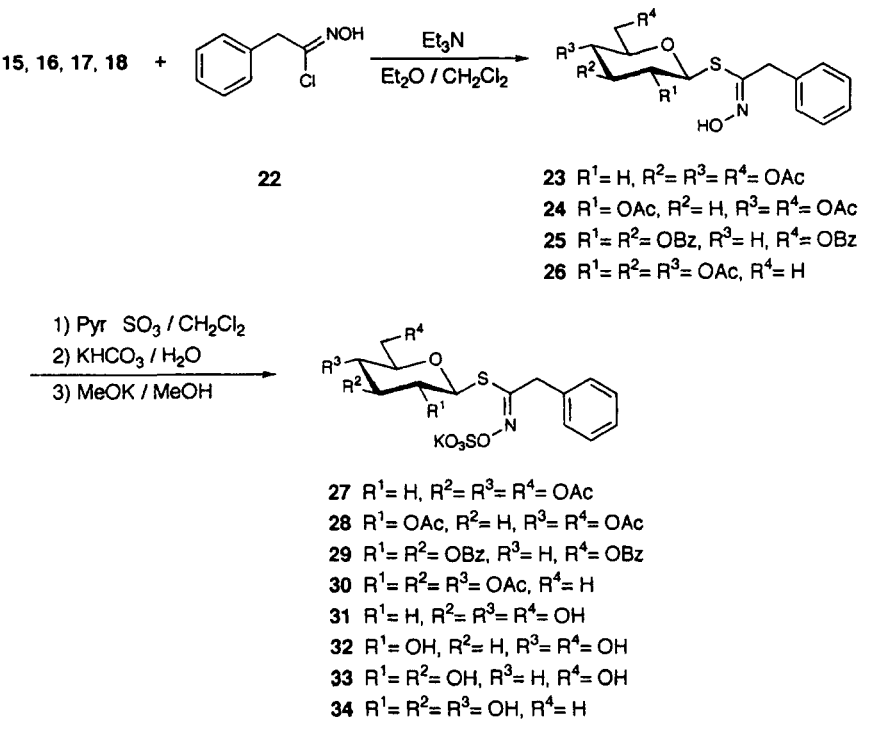


Scheme 2.

α-bromides conventionally with hydrogen bromide in acetic acid [14–16]. The Černý reaction, followed by reductive hydrolysis, yielded exclusively the β-thiols **16**, **17**, and **18** in 36, 69, and 28% yield, respectively, based on the tetra-esters. Due to the facile synthesis [17] of 1,2,3,6-tetra-*O*-benzoyl-4-deoxy-α-D-*xylo*-hexopyranose (**5**) the more stable benzoyl protection was chosen in the 4-deoxy series and this resulted in a higher overall yield than in the 2-deoxy, 3-deoxy, or 6-deoxy series with acetyl protection.

The phenylacetohydroximoyl chloride **22** needed for coupling with the thiol was prepared [18] in two steps from phenylacetaldehyde. Coupling to give the thiohydroximate was promoted by triethylamine and after purification by flash chromatography compounds **23–26** were obtained in 58–98% yield (Scheme 3). Again, the highest yield was observed for the 4-deoxy series. In all cases the coupling was stereospecific in that only the (*Z*)-isomers were formed [19]. Compounds **23–26** were pure, as could be judged by TLC and ^{1}H NMR. The subsequent sulfation was performed by using the pyridine–sulfur trioxide complex, followed by transformation into the potassium salt with potassium hydrogen carbonate to give the pro-glucosinolates (**27–30**) in yields above 70%. Deacylation with potassium methoxide and subsequent purification on a Sep-Pak C-18 cartridge yielded the desired deoxy derivatives of glucotropaeolin (**31–34**).

The synthesis of 2- and 6-deoxyglucobrassicin (**40**, **41**) followed the same synthetic scheme as for the glucotropaeolin series (Scheme 4). For the coupling, by means of

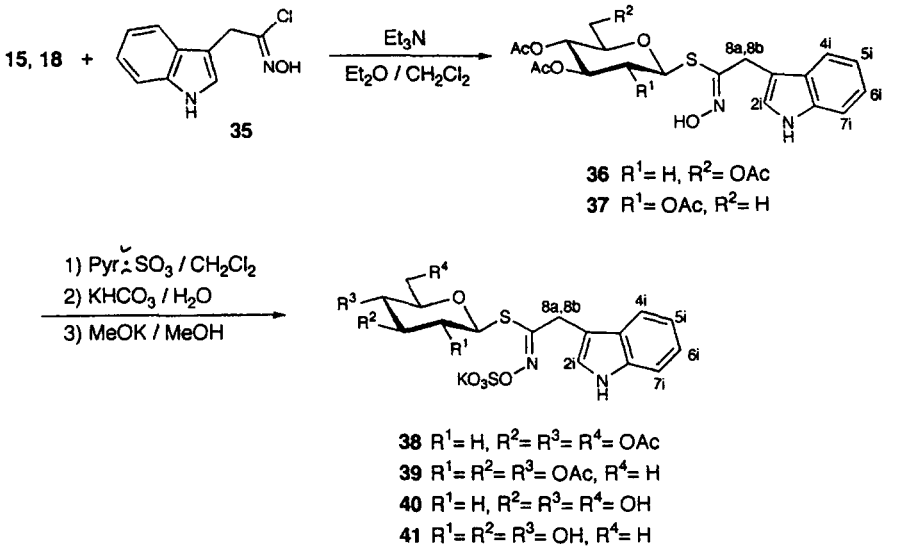


Scheme 3.

triethylamine, with the thiols the unstable indol-3-ylacetohydroximoyl chloride (**35**) had to be prepared [19] immediately before the reaction. The corresponding thiohydroximates **36** (66%) and **37** (58%) were obtained and sulfated with the pyridine–sulfur trioxide complex prepared in situ, to give **38** and **39** (69%). Due to the lability of **38**, it was used as the crude product in the final deprotection step to give **40** in 33% yield; **39** was deacetylated to afford 6-deoxyglucobrassicin (**41**) in 90% yield.

3. Experimental

^{1}H (300 and 400 MHz) and ^{13}C (100 MHz) NMR spectra were recorded on Bruker AM 300 and AMX 400 spectrometers. In the presentation of the NMR data of **36–41**, "Hi-" refers to the indole moiety. Melting points were taken on a Reichert hot-stage microscope and are uncorrected. Optical rotations were measured with a Perkin–Elmer 243 polarimeter. Flash chromatography was performed on Silica Gel 60 (Merck, 230–400 mesh). Detection was by UV light (254 nm) or by spraying with 7:2:1 EtOH–H_2O–H_2SO_4 and subsequent heating. Sep-Pak C-18 cartridges were purchased from Millipore Waters Associates. Freeze-drying was performed with a Lyovac GT 2 (Leybold–Heraeus) and pH-values were measured with a pH-meter (WTW pH 521) or with indicator strips (Merck).



Scheme 4.

3,4,6-Tri-O-acetyl-2-deoxy-1-thio-α,β-D-arabino-hexopyranose (**15**).—Thiourea (265 mg, 3.5 mmol) was added to a solution of 3,4,6-tri-*O*-acetyl-2-deoxy-α-D-*arabino*-hexopyranosyl bromide [9] (**7**, 3 mmol) in anhyd acetone (20 mL). The mixture was refluxed for 30 min and then kept overnight at room temperature. It was concentrated under reduced pressure and chromatographed on silica gel (7:3 petroleum ether–EtOAc). *S*-(3,4,6-Tri-*O*-acetyl-2-deoxy-D-*arabino*-hexopyranosyl)isothiouronium bromide (**11**) was applied in the next step without further purification. Some by-products could be isolated (**19–21**).

To **11** (ca. 2.27 mmol) a solution of $K_2S_2O_5$ (500 mg, 2.27 mmol) in water (2 mL) and CH_2Cl_2 (5 mL) was added. The reaction mixture was kept under reflux at 85°C for 20 min. The aqueous layer was separated and extracted three times with CH_2Cl_2. The combined organic phases were dried with $MgSO_4$, concentrated under reduced pressure, and chromatographed on silica gel (10:1 toluene–EtOAc). Yield of **15**: 333 mg (36% based on **3**); ^{1}H NMR (400 MHz, $CDCl_3$): (*a*) α-anomer: δ 5.76 (ddd ~ t, 0.5 H, H-1), 5.26 (ddd, 0.5 H, H-3), 4.99 (dd ~ t, 0.5 H, H-4), 4.41 (ddd, 0.5 H, H-5), 4.32 (dd, 0.5 H, H-6a), 4.09 (dd, 0.5 H, H-6b), 2.29 (ddd ~ dd, 0.5 H, H-2eq), 2.17 (d, 0.5 H, SH), 2.16 (ddd, 0.5 H, H-2ax); $J_{1,SH}$ 5.0, $J_{1,2ax}$ 4.5, $J_{1,2eq}$ 1.0, $J_{2ax,2eq}$ 13.5, $J_{2ax,3}$ 11.0, $J_{2eq,3}$ 5.5, $J_{3,4}$ 9.5, $J_{4,5}$ 10.5, $J_{5,6a}$ 4.5, $J_{5,6b}$ 2.0, $J_{6a,6b}$ 12.5 Hz; (*b*) β-anomer: δ 4.99 (ddd, 0.5 H, H-3), 4.99 (dd ~ t, 0.5 H, H-4), 4.73 (ddd, 0.5 H, H-1), 4.24 (dd, 0.5 H, H-6a), 4.09 (dd, 0.5 H, H-6b), 3.63 (ddd, 0.5 H, H-5), 2.53 (ddd, 0.5 H, H-2eq), 2.47 (d, 0.5 H, SH), 1.84 (ddd, 0.5 H, H-2ax); $J_{1,SH}$ 8.5, $J_{1,2ax}$ 12.0, $J_{1,2eq}$ 2.0, $J_{2ax,2eq}$ 12.5, $J_{2ax,3}$ 12.0, $J_{2eq,3}$ 4.0, $J_{3,4}$ 9.5, $J_{4,5}$ 9.5, $J_{5,6a}$ 5.0, $J_{5,6b}$ 2.0, $J_{6a,6b}$ 12.5 Hz; δ 2.09–2.02 (m, 9 H, 3 × OAc), not assigned to the individual anomers; MS (CI, NH_3): *m/z* 324 $[M + NH_4]^+$, 273 $[M - SH]^+$, 213 $[273 - HOAc]^+$, 153 $[213 - HOAc]^+$, 111 $[153 - C_2H_2O]^+$. Anal. Calcd for $C_{12}H_{18}O_7S$: C, 47.05; H, 5.92. Found: C, 47.36; H, 5.94.

Also isolated was *N*-(3,4,6-tri-*O*-acetyl-2-deoxy-D-*arabino*-hexopyranosyl)thiourea (**20**); ^{1}H NMR (400 MHz, $CDCl_3$): α-anomer: δ 5.44 (bd, 0.5 H, H-1), 5.39 (ddd, 0.5 H, H-3), 5.01 (dd ~ t, 0.5 H, H-4), 4.28 (dd, 0.5 H, H-6a), 4.24 (ddd ~ m, 0.5 H, H-5), 4.10 (dd, 0.5 H, H-6b), 3.07 (bs, 0.5 H, C–N*H*–CS), 2.29 (ddd ~ dd, 0.5 H, H-2eq), 2.10, 2.06, 2.03 (3 s, each 1.5 H, 3 × OAc), 1.82 (ddd, 0.5 H, H-2ax); $J_{1,2ax}$ 3.5, $J_{1,2eq}$ 1.5, $J_{2ax,2eq}$ 13.0, $J_{2ax,3}$ 12.0, $J_{2eq,3}$ 5.0, $J_{3,4}$ 9.5, $J_{4,5}$ 10.0, $J_{5,6a}$ 4.5, $J_{5,6b}$ 2.0, $J_{6a,6b}$ 11.5 Hz; the assignment of C–N*H*–CS is tentative; MS (CI, NH_3): m/z 349 $[M + H]^+$.

2,4,6-Tri-O-acetyl-3-deoxy-1-thio-β-D-ribo-hexopyranose (**16**).—Crude tri-*O*-acetyl-3-deoxy-α-D-*ribo*-hexopyranosyl bromide **8** [16] (ca. 12 mmol) was dissolved with stirring in anhyd acetone (60 mL) under N_2. Thiourea (915 mg, 12 mmol) was added and the solution refluxed for 60 min, cooled, and concentrated to dryness under reduced pressure. The residue was taken up in CH_2Cl_2 (15 mL), filtered, and the resulting filtrate, devoid of unreacted thiourea, was concentrated to give 2,4,6-tri-*O*-acetyl-3-deoxy-β-D-*ribo*-hexopyranosylisothiouronium bromide (**12**) as an oil that was used in the next step without further purification.

To the crude **12** (ca. 12 mmol) a solution of $K_2S_2O_5$ (2.23 g, 10 mmol) in water (8 mL) and CH_2Cl_2 (20 mL) was added and refluxed for 40 min. The aqueous phase was extracted with CH_2Cl_2. The extracts were washed with water, dried over $MgSO_4$, and concentrated under reduced pressure. The resulting syrup was chromatographed on silica gel (4:1 toluene–EtOAc) to afford **16** as a colourless syrup (1.32 g, 36% based on **4**); $[\alpha]_D^{20}$ +25° (*c* 0.8, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.81 (ddd, 1 H, H-2), 4.75 (ddd, 1 H, H-4), 4.45 (dd ~ t, 1 H, H-1), 4.17 (dd, 1 H, H-6a), 4.13 (dd, 1 H, H-6b), 3.61 (ddd, 1 H, H-5), 2.56 (ddd ~ dt, 1 H, H-3eq), 2.17 (d, 1 H, SH), 2.05, 2.00 (2 s, 9 H, 3 × OAc), 1.57 (ddd ~ dd, 1 H, H-3ax); $J_{1,SH}$ 9.0, $J_{1,2}$ 9.5, $J_{2,3ax}$ 11.5, $J_{2,3eq}$ 5.0, $J_{3ax,3eq}$ 12.0, $J_{3ax,4}$ 11.5, $J_{3eq,4}$ 5.0, $J_{4,5}$ 10.2, $J_{5,6a}$ 4.5, $J_{5,6b}$ 3.0, $J_{6a,6b}$ 12.0 Hz. Anal. Calcd for $C_{12}H_{18}O_7S$: C, 47.05; H, 5.92. Found: C, 47.11; H, 5.95.

2,3,6-Tri-O-benzoyl-4-deoxy-1-thio-β-D-xylo-hexopyranose (**17**).—1,2,3,6-Tetra-*O*-benzoyl-4-deoxy-α-D-*xylo*-hexopyranose (**5**, 2.0 g, 3.44 mmol) was dissolved in CH_2Cl_2 (3 mL) and HBr (2.5 mL, 33% solution in HOAc) was added dropwise at 4°C. The solution was stirred at room temperature for 60 min and codistilled several times with toluene and with ether. 2,3,6-Tri-*O*-benzoyl-4-deoxy-α-D-*xylo*-hexopyranosyl bromide (**9**) was used in the next step without further purification; ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.11–7.88 (m, 6 H, *o*-Ph-H), 7.63–7.31 (m, 9 H, *m*- + *p*-Ph-H), 6.83 (d, 1 H, H-1), 5.87 (ddd, 1 H, H-3), 5.31 (dd, 1 H, H-2), 4.68 (m, 1 H, H-5), 4.50 (m, 2 H, H-6a,6b), 2.58 (ddd, 1 H, H-4eq), 2.03 (ddd ~ dd, 1 H, H-4ax); $J_{1,2}$ 4.5, $J_{2,3}$ 10.5, $J_{3,4ax}$ 12.0, $J_{3,4eq}$ 3.5, $J_{4ax,4eq}$ 12.0, $J_{4ax,5}$ 12.0, $J_{4eq,5}$ 5.5 Hz.

A solution of crude **9** (ca. 3.44 mmol) and thiourea (320 mg, 4.13 mmol) in anhyd acetone (24 mL) under N_2 was refluxed for 60 min. Work-up procedure as for **12** gave 2,3,6-tri-*O*-benzoyl-4-deoxy-β-D-*xylo*-hexopyranosylisothiouronium bromide (**13**).

To the crude isothiouronium bromide **13** (ca. 3.44 mmol) a solution of $K_2S_2O_5$ (780 mg, 3.44 mmol) in water (4 mL) and CH_2Cl_2 (8 mL) was added and refluxed for 30 min. Work-up procedure was the same as for **16**. The resulting syrup was chromatographed on silica gel (20:1 toluene–EtOAc) to afford **17** as a colourless syrup (1.17 g, 69% based on **5**); $[\alpha]_D^{20}$ +75° (*c* 0.9, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.06–7.90 (m, 6 H, *o*-Ph-H), 7.59–7.10 (m, 9 H, *m*- + *p*-Ph-H), 5.40 (ddd, 1 H, H-3),

5.36 (dd, 1 H, H-2), 4.76 (dd ~ t, 1 H, H-1), 4.47 (dd, 1 H, H-6a), 4.42 (dd, 1 H, H-6b), 4.08 (m, 1 H, H-5), 2.53 (ddd, 1 H, H-4eq), 2.41 (d, 1 H, SH), 1.95 (ddd, 1 H, H-4ax); $J_{1,SH}$ 9.5, $J_{1,2}$ 9.5, $J_{2,3}$ 9.0, $J_{3,4ax}$ 12.0, $J_{3,4eq}$ 3.5, $J_{4ax,4eq}$ 12.0, $J_{4ax,5}$ 12.0, $J_{4eq,5}$ 1.5, $J_{5,6a}$ 5.5, $J_{5,6b}$ 4.5, $J_{6a,6b}$ 12.0 Hz. Anal. Calcd for $C_{27}H_{24}O_7S$: C, 65.84; H, 4.91. Found: C, 65.11; H, 4.87.

*2,3,4-Tri-*O*-acetyl-6-deoxy-1-thio-β-*D*-glucopyranose* (**18**).—A solution of crude tri-*O*-acetyl-6-deoxy-α-D-glucopyranosyl bromide **10** [15] (ca. 1.3 mmol) in anhyd acetone (10 mL) under N_2 was refluxed with thiourea (120 mg, 1.6 mmol) for 60 min. Work-up procedure as for **12** gave 2,3,4-tri-*O*-acetyl-6-deoxy-β-D-glucopyranosylisothiouronium bromide (**14**).

To the crude **14** (ca. 1.3 mmol) a solution of $K_2S_2O_5$ (120 mg, 1.3 mmol) in water (2 mL) and CH_2Cl_2 (5 mL) was added and refluxed for 30 min. Work-up procedure as for **16** yielded **18** as a colourless oil, which crystallized readily; yield: 110 mg (28% referred to **6**); mp 118°C; $[\alpha]_D^{20}$ +2° (*c* 1.0, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 5.11 (dd ~ t, 1 H, H-3), 4.91 (dd ~ t, 1 H, H-2), 4.81 (dd ~ t, 1 H, H-4), 4.48 (dd ~ t, 1 H, H-1), 3.56 (dq, 1 H, H-5), 2.22 (d, 1 H, SH), 2.04, 2.01, 1.97 (3 s, each 3 H, 3 × OAc), 1.25 (d, 3 H, H-6); $J_{1,SH}$ 9.5, $J_{1,2}$ 9.5, $J_{2,3}$ 9.5, $J_{3,4}$ 9.5, $J_{4,5}$ 9.5, $J_{5,6}$ 6.5 Hz. Anal. Calcd for $C_{12}H_{18}O_7S$: C, 47.05; H, 5.92. Found: C, 47.32; H, 5.94.

S-*(3,4,6-Tri-*O*-acetyl-2-deoxy-*D*-arabino-hexopyranosyl) phenylacetothiohydroximate* (**23**).—A suspension of the hydroximoyl chloride **22** (980 mg, 25.8 mmol) in 2:1 Et_2O–CH_2Cl_2 (45 mL) was mixed with a solution of **15** (710 mg, 2.3 mmol) in anhyd CH_2Cl_2 (3.5 mL). Et_3N (1.05 mL, 7.6 mmol) was added. The mixture was stirred for 60 min under Ar, then concentrated under reduced pressure, dissolved in CH_2Cl_2, and washed with water. The organic phase was dried over $MgSO_4$, concentrated, and chromatographed on silica gel (6:1 toluene–EtOAc) to yield **23** as a white foam (609 mg, 66%); ^{1}H NMR (400 MHz, $CDCl_3$): (a) α-anomer: δ 5.65 (d, 0.3 H, H-1), 5.17 (ddd, 0.3 H, H-3), 4.89 (dd ~ t, 0.3 H, H-4), 4.22 (dd, 0.3 H, H-6a), 4.16 (dd, 0.3 H, H-6b), 3.92 (s, 0.6 H, C*H*$_2$-Ph), 3.82 (m, 0.3 H, H-5), 2.15 (m, 0.3 H, H-2eq), 2.02, 1.96, 1.92 (3 s, each 0.9 H, 3 × OAc), 2.00 (m, 0.3 H, H-2ax); $J_{1,2ax}$ 5.0, $J_{1,2eq}$ < 1.0, $J_{2ax,2eq}$ 12.0, $J_{2ax,3}$ 12.0, $J_{2eq,3}$ 5.0, $J_{3,4}$ 9.5, $J_{4,5}$ 9.5, $J_{5,6a}$ 5.0, $J_{5,6b}$ 2.0, $J_{6a,6b}$ 12.5 Hz; (b) β-anomer: δ 4.86 (dd ~ t, 0.7 H, H-4), 4.78 (ddd, 0.7 H, H-3), 4.67 (dd, 0.7 H, H-1), 4.12 (dd, 0.7 H, H-6a), 4.02 (dd, 0.7 H, H-6b), 3.92 (s, 1.4 H, C*H*$_2$-Ph), 3.45 (ddd, 0.7 H, H-5), 2.14 (ddd, 0.7 H, H-2eq), 2.04, 1.96, 1.93 (3 s, each 2.1 H, 3 × OAc), 1.71 (ddd ~ dd, 0.7 H, H-2ax); $J_{1,2ax}$ 12.0, $J_{1,2eq}$ 2.0, $J_{2ax,2eq}$ 12.0, $J_{2ax,3}$ 12.0, $J_{2eq,3}$ 5.5, $J_{3,4}$ 9.5, $J_{4,5}$ 9.5, $J_{5,6a}$ 6.0, $J_{5,6b}$ 2.5, $J_{6a,6b}$ 12.0 Hz; δ 7.69, 7.72 (2 bs, 2 H, 2 × NO*H*), 7.32–7.07 (m, 5 H, Ph-H), not assigned to the individual anomers.

S-*(2,4,6-Tri-*O*-acetyl-3-deoxy-β-*D*-ribo-hexopyranosyl) phenylacetothiohydroximate* (**24**).—Hydroximoyl chloride **22** (1.41 g, 8.3 mmol) in 2:1 Et_2O–CH_2Cl_2 (66 mL) was mixed with a solution of **16** (3.3 mmol, 1.02 g) in anhyd CH_2Cl_2 (4 mL) and Et_3N (1.5 mL, 11 mmol) under Ar. The mixture was stirred for 60 min at room temperature. Work-up procedure as for **23** yielded **24** as an amorphous white solid (1.185 g, 81%); $[\alpha]_D^{20}$ +1° (*c* 0.8, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.72 (bs, 1 H, NO*H*), 7.33–7.14 (m, 5 H, Ph-H), 4.72 (ddd ~ dd, 1 H, H-2), 4.69 (ddd ~ dd, 1 H, H-4), 4.63 (d, 1 H, H-1), 4.08 (dd, 1 H, H-6a), 4.03 (dd, 1 H, H-6b), 3.95, 3.90 (2 d, 2 H, C*H*$_2$-Ph, ^2J 16.5 Hz), 3.45 (ddd, 1 H, H-5), 2.53 (ddd, 1 H, H-3eq), 2.01, 1.96, 1.91 (3 s, each 3

H, 3 × OAc), 1.38 (dd, 1 H, H-3ax); $J_{1,2}$ 10.5, $J_{2,3ax}$ 11.0, $J_{2,3eq}$ 5.0, $J_{3ax,3eq}$ 12.0, $J_{3ax,4}$ 11.0, $J_{3eq,4}$ 5.0, $J_{4,5}$ 9.5, $J_{5,6a}$ 3.0, $J_{5,6b}$ 6.0, $J_{6a,6b}$ 12.0 Hz.

S-(2,3,6-Tri-O-benzoyl-4-deoxy-β-D-xylo-hexopyranosyl) phenylacetothiohydroximate (**25**).—Hydroximoyl chloride **22** (850 mg, 5 mmol) in 2:1 Et_2O–CH_2Cl_2 (40 mL) was mixed with a solution of **17** (1.0 g) in anhyd CH_2Cl_2 (4 mL) and Et_3N (0.95 mL, 6.6 mmol) under Ar. The mixture was stirred for 60 min at room temperature. Work-up procedure as for **23** yielded **25** as a white foam (1.3 g, 98%); $[\alpha]_D^{20}$ +64° (*c* 0.9, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.10–7.77 (m, 8 H, *o*-Ph-H), 7.60–7.14 (m, 12 H, *m*- + *p*-Ph-H), 5.39 (dd ~ t, 1 H, H-2), 5.18 (ddd, 1 H, H-3), 4.98 (d, 1 H, H-1), 4.44 (dd, 1 H, H-6a), 4.40 (dd, 1 H, H-6b), 3.99 (m, 1 H, H-5), 3.95 (s, 2 H, CH_2-Ph), 2.45 (ddd, 1 H, H-4eq), 1.85 (ddd ~ dd, 1 H, H-4ax); $J_{1,2}$ 10.0, $J_{2,3}$ 9.5, $J_{3,4ax}$ 11.0, $J_{3,4eq}$ 5.0, $J_{4ax,4eq}$ 13.5, $J_{4ax,5}$ 11.0, $J_{4eq,5}$ 2.0, $J_{5,6a}$ 4.0, $J_{5,6b}$ 6.5, $J_{6a,6b}$ 12.0 Hz.

S-(2,3,4-Tri-O-acetyl-6-deoxy-β-D-glucopyranosyl) phenylacetothiohydroximate (**26**). —Hydroximoyl chloride **22** (152 mg, 898 μmol) in 2:1 Et_2O–CH_2Cl_2 (7 mL) was mixed with a solution of **18** (110 mg, 359 μmol) in anhyd CH_2Cl_2 (1 mL) and Et_3N (0.17 mL, 1.19 mmol) under Ar. The mixture was stirred for 60 min at room temperature. Work-up procedure as for **23** yielded **26** as a white foam (91 mg, 58%); $[\alpha]_D^{20}$ +1° (*c* 0.8, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.67 (bs, 1 H, NO*H*), 7.40–7.23 (m, 5 H, Ph-H), 4.78 (d, 1 H, H-1), 5.01 (dd ~ t, 1 H, H-3), 4.93 (dd ~ t, 1 H, H-2), 4.78 (dd ~ t, 1 H, H-4), 3.96, 3.87 (2 d, 2 H, CH_2-Ph, ^2J 16.0 Hz), 3.32 (m, 1 H, H-5), 2.02, 1.97, 1.96 (3 s, each 3 H, 3 × OAc), 1.16 (d, 3 H, H-6); $J_{1,2}$ 9.5, $J_{2,3}$ 9.5, $J_{3,4}$ 9.5, $J_{4,5}$ 9.5, $J_{5,6}$ 6.5 Hz.

S-(3,4,6-Tri-O-acetyl-2-deoxy-α,β-D-arabino-hexopyranosyl) O-(potassium sulfonato)phenylacetothiohydroximate (2-deoxy-glucotropaeolin triacetate, **27**).—The pyridine–sulfur trioxide complex was prepared by mixing carefully a solution of pyridine (7.3 mL, 90 mmol) in anhyd CH_2Cl_2 (13 mL) with a solution of chlorosulfonic acid (0.85 mL, 13 mmol) in CH_2Cl_2 (4 mL). A solution of **23** (566 mg, 1.29 mmol) in CH_2Cl_2 (8 mL) was added and the mixture was stirred for 24 h under Ar. The potassium salt was prepared by adding a solution of $KHCO_3$ (645 mg, 6.45 mmol) in water (10 mL). The mixture was stirred for 30 min and afterwards concentrated under reduced pressure. To remove excess of pyridine the mixture was codistilled several times with toluene; **27** was purified by flash chromatography (CH_2Cl_2/0–5% MeOH) and obtained as an amorphous white solid (543 mg, 76%); ^{1}H NMR (300 MHz, Me_2SO): α-anomer: δ 5.68 (m, 0.3 H, H-1), 4.91 (m, 0.3 H, H-3), 4.79 (dd ~ t, 0.3 H, H-4), 3.93 (s, 0.6 H, CH_2-Ph), 2.14–1.85 (m, 0.6 H, H-2ax, H-2eq); β-anomer: δ 5.07 (dd, 0.7 H, H-1), 4.91 (m, 0.7 H, H-3), 4.72 (dd ~ t, 0.7 H, H-4), 3.93 (s, 1.4 H, CH_2-Ph), 2.05 (m, 0.7 H, H-2eq), 1.64 (dd, 0.7 H, H-2ax); $J_{1,2ax}$ 11.0, $J_{1,2eq} < 1.0$, $J_{2ax,2eq}$ 11.0, $J_{3,4}$ 9.5, $J_{4,5}$ 9.5 Hz; δ 7.35–7.18 (m, 5 H, Ph-H), 4.15–3.65 (m, 6 H, remaining sugar protons, 2 × H-5, 4 × H-6), not assigned to the individual anomers.

S-(2,4,6-Tri-O-acetyl-3-deoxy-β-D-ribo-hexopyranosyl) O-(potassium sulfonato)phenylacetothiohydroximate (3-deoxy-glucotropaeolin triacetate, **28**).—Compound **28** was prepared in the same way as **27** with the following solutions: (*a*) pyridine (14 mL, 175 mmol) in CH_2Cl_2 (25 mL), (*b*) $ClSO_3H$ (1.7 mL, 25 mmol) in CH_2Cl_2 (8 mL), (*c*) **24** (1.1 g, 2.5 mmol) in CH_2Cl_2 (15 mL), (*d*) $KHCO_3$ (1.25 g, 12.5 mmol) in water (20 mL); yield: 1.0 g (72%); ^{1}H NMR (300 MHz, Me_2SO): δ 7.40–7.25 (m, 5 H, Ph-H),

4.91 (d, 1 H, H-1), 4.73–4.57 (m, 2 H, H-2, H-4), 4.04 (dd, 1 H, H-6a), 3.97 (s, 2 H, CH_2-Ph), 3.94 (m, 1 H, H-6b), 3.75 (m, 1 H, H-5), 2.40 (ddd ~ dt, 1 H, H-3eq), 2.00, 1.99, 1.92 (3 s, each 3 H, 3 × OAc), 1.58 (ddd ~ dd, H-3ax); $J_{1,2}$ 10.5, $J_{2,3ax}$ 11.5, $J_{2,3eq}$ 4.5, $J_{3ax,3eq}$ 11.5, $J_{3ax,4}$ 11.5, $J_{3eq,4}$ 4.5, $J_{5,6a}$ 6.0, $J_{6a,6b}$ 12.0 Hz.

S-*(2,3,6-Tri*-O-*benzoyl-4-deoxy-β*-D-xylo-*hexopyranosyl)* O-*(potassium sulfonato)phenylacetothiohydroximate (4-deoxy-glucotropaeolin tribenzoate,* **29**).—Compound **29** was prepared in the same way as **27** with the following solutions: (*a*) pyridine (10.5 mL, 130 mmol) in CH_2Cl_2 (20 mL), (*b*) $ClSO_3H$ (1.3 mL, 18.5 mmol) in CH_2Cl_2 (6 mL), (*c*) **25** (1.15 g, 1.84 mmol) in CH_2Cl_2 (11 mL), (*d*) $KHCO_3$ (1.0 g, 10 mmol) in water (15 mL); yield: 1.0 g (73%); ^{1}H NMR (300 MHz, Me_2SO): δ 8.02–7.20 (m, 20 H, Ph-H), 5.43 (m, 1 H, H-3), 5.29 (d, 1 H, H-1), 5.18 (dd ~ t, 1 H, H-2), 4.40–4.21 (m, 3 H, H-5, H-6a, H-6b), 3.97, 3.90 (2 d, 2 H, CH_2-Ph, ^2J 16.0 Hz), 2.36 (ddd ~ dd, 1 H, H-4eq), 1.93 (ddd ~ dd, 1 H, H-4ax); $J_{1,2}$ 10.5, $J_{2,3}$ 9.0, $J_{3,4ax}$ 12.0, $J_{3,4eq}$ 5.0, $J_{4ax,4eq}$ 12.0 Hz.

S-*(2-Deoxy-α,β-*D-arabino-*hexopyranosyl)* O-*(potassium sulfonato)phenylacetothiohydroximate (2-deoxy-glucotropaeolin,* **31**).—To **27** (540 mg, 968 μmol), dissolved in anhyd MeOH (50 mL), a 0.8 M solution of MeOK in MeOH was carefully added until pH 8.0. After 3 h stirring under Ar, the solution was concentrated under reduced pressure, taken up in H_2O, and purified using a Sep-Pak C-18 cartridge. After elution with water and freeze-drying, **31** was obtained as a white powder (260 mg, 62%); α-anomer: ^{1}H NMR (400 MHz, D_2O): δ 5.68 (dd ~ d, 0.3 H, H-1), 3.77 (m, 0.3 H, H-3), 3.72 (ddd, 0.3 H, H-5), 3.65–3.58 (m, 0.3 H, H-6a), 3.43 (m, 0.3 H, H-6b), 3.26 (dd ~ t, 0.3 H, H-4), 2.05–1.96 (m, 0.3 H, H-2eq), 1.84 (ddd, 0.3 H, H-2ax); $J_{1,2ax}$ 6.0, $J_{1,2eq}$ < 1.0, $J_{2ax,2eq}$ 12.0, $J_{2ax,3}$ 12.0, $J_{3,4}$ 9.5, $J_{4,5}$ 9.5 Hz; ^{13}C NMR (100 MHz, D_2O): δ 163.38 (C=N), 135.97 (C-1 of Ph), 129.49, 128.67 (*m*- + *o*-Ph-C), 127.84 (*p*-Ph-C), 78.61 (C-1), 73.95 (C-5), 71.19 (C-4), 68.79 (C-3), 60.48 (C-6), 38.07 (CH_2-Ph), 37.18 (C-2); β-anomer: ^{1}H NMR (400 MHz, D_2O): δ 4.84 (dd, 0.7 H, H-1), 3.65–3.58 (m, 1.4 H, H-6a, H-6b), 3.47 (m, 0.7 H, H-3), 3.23–3.16 (m, 1.4 H, H-4, H-5), 2.05–1.96 (m, 0.7 H, H-2eq), 1.53 (ddd ~ dd, 0.7 H, H-2ax), $J_{1,2ax}$ 12.0, $J_{1,2eq}$ 2.0, $J_{2ax,2eq}$ 12.0, $J_{2ax,3}$ 12.0 Hz; ^{13}C NMR (100 MHz, D_2O): δ 163.38 (C=N), 135.73 (C-1 of Ph), 129.62, 128.56 (*m*- + *o*-Ph-C), 127.98 (*p*-Ph-C), 80.47 (C-5), 76.30 (C-1), 71.72 (C-3), 70.59 (C-4), 61.05 (C-6), 38.48 (C-2), 38.07 (CH_2-Ph); ^{1}H, δ 7.39–7.25 (m, 5 H, Ph-H), 4.13–3.95 (2 d, 2 H, CH_2-Ph), not assigned to the individual anomers. Anal. Calcd for $C_{14}H_{18}KNO_8S_2 \cdot H_2O$: C, 37.41; H, 4.48; N, 3.12. Found: C, 37.01; H, 4.45; N, 3.12.

S-*(3-Deoxy-β-*D-ribo-*hexopyranosyl)* O-*(potassium sulfonato)phenylacetohydroximate (3-deoxy-glucotropaeolin,* **32**).—Compound **28** (100 mg, 179 μmol) was dissolved in anhyd MeOH (10 mL). A pH value of 8.0 was attained with 0.8 M methanolic MeOK. After stirring for 3 h under Ar the product was isolated in the same way as **31**; **32** was obtained as a white powder (58 mg, 75%); $[\alpha]_D^{20}$ −19° (*c* 1.0, H_2O); ^{1}H NMR (400 MHz, D_2O): δ 7.40–7.26 (m, 5 H, Ph-H), 4.51 (d, 1 H, H-1), 4.04, 4.09 (2 d, 2 H, CH_2-Ph, ^2J 17.0 Hz), 3.61 (dd, 1 H, H-6a), 3.55–3.40 (m, 3 H, H-2, H-4, H-6b), 3.10 (m, 1 H, H-5), 2.34 (ddd ~ dt, 1 H, H-3eq), 1.28 (ddd ~ dd, 1 H, H-3ax); $J_{1,2}$ 9.5, $J_{2,3ax}$ 12.5, $J_{2,3eq}$ 5.0, $J_{3ax,3eq}$ 12.0, $J_{3ax,4}$ 12.0, $J_{3eq,4}$ 5.0 Hz; ^{13}C NMR (100 MHz, $CDCl_3$): δ 163.32 (C=N), 135.61 (C-1 of Ph), 129.60, 128.53 (*o*- + *m*-Ph-C), 127.96 (*p*-Ph-C),

83.94 (C-1), 82.77 (C-5), 67.19 (C-2), 64.09 (C-4), 60.88 (C-6), 40.53 (C-3), 38.64 (CH_2-Ph). Anal. Calcd for $C_{14}H_{18}KNO_8S_2 \cdot H_2O$: C, 37.41; H, 4.48; N, 3.12. Found: C, 37.37; H, 4.53; N, 3.12.

S-*(4-Deoxy-β-*D-xylo-*hexopyranosyl)* O-*(potassium sulfonato)phenylacetothiohydroximate (4-deoxy-glucotropaeolin,* **33**).—Compound **29** (900 mg, 1.21 mmol) was dissolved in anhyd MeOH (60 mL). A pH value of 9.5 was attained with 0.8 M methanolic MeOK. After stirring for 3 h under Ar the product was isolated in the same way as **31**; **33** was obtained as a white powder (430 mg, 82%); $[\alpha]_D^{20}$ −10° (*c* 0.7, H_2O); ^{1}H NMR (400 MHz, D_2O): δ 7.40–7.23 (m, 5 H, Ph-H), 4.57 (d, 1 H, H-1), 4.09, 4.03 (2 d, 2 H, CH_2-Ph, ^2J 16.5 Hz), 3.51–3.43 (m, 2 H, H-3, H-5), 3.41 (dd, 1 H, H-6a), 3.35 (dd, 1 H, H-6b), 3.14 (dd ~ t, 1 H, H-2), 1.88 (ddd, 1 H, H-4eq), 1.33 (ddd ~ dd, 1 H, H-4ax); $J_{1,2}$ 9.5, $J_{2,3}$ 9.5, $J_{3,4ax}$ 12.0, $J_{3,4eq}$ 5.0, $J_{4ax,4eq}$ 13.0, $J_{5,6a}$ 4.5, $J_{5,6b}$ 6.0, $J_{6a,6b}$ 12.0 Hz; ^{13}C NMR (100 MHz, $CDCl_3$): δ 161.75 (C=N), 134.04 (C-1 of Ph), 128.03, 126.95 (*m*- + *o*-Ph-C), 126.39 (*p*-Ph-C), 80.54 (C-1), 75.60, 70.22 (C-3, C-5), 72.02 (C-2), 62.12 (C-6), 37.05 (CH_2-Ph), 32.74 (C-4). Anal. Calcd for $C_{14}H_{18}KNO_8S_2 \cdot H_2O$: C, 37.41; H, 4.48; N, 3.12. Found: C, 37.78; H, 4.47; N, 3.03.

S-*(6-Deoxy-β-*D-*glucopyranosyl)* O-*(potassium sulfonato)phenylacetothiohydroximate (6-deoxy-glucotropaeolin,* **34**).—6-Deoxy-glucotropaeolin triacetate (**30**) was prepared in the same way as **27** with the following solutions: (*a*) pyridine (1.2 mL, 14.5 mmol) in CH_2Cl_2 (2.1 mL), (*b*) $ClSO_3H$ (0.14 mL, 2.07 mmol) in CH_2Cl_2 (0.64 mL), (*c*) **26** (91 mg, 207 μmol) in CH_2Cl_2 (1.3 mL), (*d*) $KHCO_3$ (104 mg, 1.04 mmol) in water (1.6 mL); **30** was partially purified by flash chromatography (CH_2Cl_2/0–5% MeOH) and was applied in the next step as a crude product.

The crude **30** (ca. 100 mg, 180 μmol) was dissolved in anhyd MeOH (10 mL). A pH value of 8.0 was attained using 0.8 M methanolic MeOK. After stirring for 3 h under Ar the product was isolated in the same way as **31**; **34** was obtained as a white powder (33 mg, 37% based on **26**, 2 steps); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.35–7.25 (m, 5 H, Ph-H), 4.56 (d, 1 H, H-1), 4.02, 3.99 (2 d, 2 H, CH_2-Ph, ^2J 13.0 Hz), 3.22–2.94 (m, 4 H, H-2, H-3, H-4, H-5), 0.94 (d, 3 H, H-6); ^{13}C NMR (100 MHz, $CDCl_3$): δ 161.53 (C=N), 134.12 (C-1 of Ph), 128.32, 127.15 (*m*- + *o*-Ph-C), 126.70 (*p*-Ph-C), 80.53, 75.77, 75.29, 73.37, 71.14 (C-1, C-2, C-3, C-4, C-5), 37.36 (CH_2-Ph), 15.87 (C-6). Anal. Calcd for $C_{14}H_{18}KNO_8S_2 \cdot H_2O$: C, 37.41; H, 4.48; N, 3.12. Found: C, 37.33; H, 4.53; N, 3.12.

S-*(3,4,6-Tri-*O-*acetyl-2-deoxy-α,β-*D-arabino-*hexopyranosyl indol-3-yl)acetothiohydroximate* (**36**).—A suspension of **35** (500 mg, 2.4 mmol) in anhyd 2:1 Et_2O–CH_2Cl_2 (20 mL) was mixed with a solution of **15** (312 mg, 1.02 mmol) in anhyd CH_2Cl_2 (1.5 mL). Triethylamine (310 mg, 3.06 mmol) was added and the mixture was kept overnight under Ar. The mixture was concentrated under reduced pressure and dissolved in CH_2Cl_2. The solution was washed with water, dried over $MgSO_4$, concentrated, and chromatographed on silica gel; yield of **36**: 311 mg (66%); ^{1}H NMR (300 MHz, $CDCl_3$): α-anomer: δ 5.88 (dd ~ d, 0.4 H, H-1), 5.32 (ddd, 0.4 H, H-3), 4.95 (dd ~ t, 0.4 H, H-4), 4.29 (m, 0.4 H, H-5), 4.23 (dd, 0.4 H, H-6a), 3.95 (dd, 0.4 H, H-6b), 2.19 (m, 0.4 H, H-2eq), 2.00 (m, 0.4 H, H-2ax); $J_{1,2ax}$ 5.0, $J_{1,2eq}$ < 1.0, $J_{2ax,2eq}$ 12.0, $J_{2ax,3}$ 12.0, $J_{2eq,3}$ 5.0, $J_{3,4}$ 9.5, $J_{4,5}$ 9.5, $J_{5,6a}$ 5.0, $J_{5,6b}$ 2.0, $J_{6a,6b}$ 12.5 Hz; β-anomer: δ 4.91 (dd ~ t, 0.6 H, H-4), 4.90 (dd, 0.6 H, H-1), 4.76 (m, 0.6 H, H-3), 4.17 (dd, 0.6 H, H-6a),

4.05 (dd, 0.6 H, H-6b), 3.38 (ddd, 0.6 H, H-5), 2.23 (m, 0.6 H, H-2eq), 1.77 (ddd, 0.6 H, H-2ax); $J_{1,2ax}$ 12.0, $J_{1,2eq}$ 1.5, $J_{2ax,2eq}$ 12.0, $J_{2ax,3}$ 11.0, $J_{2eq,3}$ 5.0, $J_{3,4}$ 10.0, $J_{4,5}$ 10.0, $J_{5,6a}$ 6.0, $J_{5,6b}$ 2.0, $J_{6a,6b}$ 12.5 Hz; not assigned to the individual anomers: δ 8.16, 8.10 (2 bs, 1 H, NH), 7.86 (bs, 1 H, NOH), 7.64, 7.60 (2 d, 1 H, H-4i), 7.40, 7.36 (2 d, 1 H, H-7i), 7.1–7.3 (m, 5 H, H-2i, H-5i, H-6i, H-8a, H-8b), 2.09–1.98 (m, 12 H, 4 × OAc).

S-*(2,3,4-Tri-*O*-acetyl-6-deoxy-β-*D*-glucopyranosyl) indol-3-yl)acetothiohydroximate* (**37**).—To a stirred solution of **35** (230 mg, 1.1 mmol) in anhyd Et_2O (3 mL) and anhyd CH_2Cl_2 (2 mL), **18** (337 mg, 1.1 mmol) in CH_2Cl_2 (2 mL) was added, followed by Et_3N (0.5 mL, 3.7 mmol) in Et_2O (1 mL). The solution was stirred overnight under Ar. The mixture was acidified with 0.5 M H_2SO_4 (8 mL) and extracted with EtOAc. The combined extracts were washed with water to neutrality, dried over $MgSO_4$, and concentrated under reduced pressure. The remaining oil was chromatographed on silica gel (2% MeOH in CH_2Cl_2) to afford **37** (305 mg, 58%) as an amorphous white solid; $[\alpha]_D^{20}$ +1° (*c* 1.0, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.14 (s, 1 H, NH), 7.61 (d, 1 H, H-4i), 7.39 (d, 1 H, H-7i), 7.23 (dd, 1 H, H-6i), 7.15 (dd, 1 H, H-5i), 7.10 (d, 1 H, H-2i), 4.91–4.98 (m, 3 H, H-1, H-2, H-3), 4.76 (m, 1 H, H-4), 4.03, 3.98 (2 d, 2 H, H-8a, H-8b, ^2J 16.0 Hz), 3.20 (dq, 1 H, H-5), 1.98, 1.95, 1.93 (3 s, each 3 H, 3 × OAc), 1.13 (d, 3 H, H-6); $J_{4,5}$ 10.0, $J_{5,6}$ 6.0 Hz.

S-*(3,4,6-Tri-*O*-acetyl-2-deoxy-α,β-*D*-*arabino*-hexopyranosyl)* O-*(potassium sulfonato)indol-3-ylacetothiohydroximate (2-deoxy-glucobrassicin triacetate,* **38**).—The pyridine–sulfur trioxide complex was prepared by mixing a solution of pyridine (2 mL, 24 mmol) in anhyd CH_2Cl_2 (6 mL) carefully with a solution of chlorosulfonic acid (0.8 mL, 12 mmol) in CH_2Cl_2 (3 mL). A solution of **36** (270 mg, 0.56 mmol) in CH_2Cl_2 (3 mL) was added and the mixture was kept overnight under Ar. The potassium salt was prepared by adding a solution of $KHCO_3$ (146 mg, 1.4 mmol) in water (5 mL). The mixture was stirred for 30 min and concentrated under reduced pressure. To remove excess of pyridine the mixture was codistilled several times with toluene; **38** was partially purified by flash chromatography and was applied in the next step as a crude product; ^{1}H NMR (300 MHz, Me_2SO): α-anomer: δ 5.83 (dd ~ t, 0.4 H, H-1), 5.04 (ddd, 0.4 H, H-3), 4.81 (dd ~ t, 0.4 H, H-4), 4.20–3.76 (m, 0.8 H, H-6a, H-6b), 3.47 (m, 0.4 H, H-5), 2.16–2.00 (m, 0.8 H, H-2ax, H-2eq); $J_{1,2ax}$ 3.5, $J_{1,2eq}$ 3.5, $J_{2ax,3}$ 8.5, $J_{2eq,3}$ 2.0, $J_{3,4}$ 9.0, $J_{4,5}$ 9.5, $J_{5,6a}$ 4.5, $J_{5,6b}$ 4.5 Hz; β-anomer: δ 5.25 (dd ~ d, 0.6 H, H-1), 4.96 (m, 0.6 H, H-3), 4.74 (dd ~ t, 0.6 H, H-4), 4.20–3.76 (m, 1.2 H, H-6a, H-6b), 3.76 (ddd, 0.6 H, H-5), 2.16–2.00 (m, 0.6 H, H-2eq), 1.65 (m, 0.6 H, H-2ax); $J_{1,2ax}$ 11.5, $J_{1,2eq} < 1.0$, $J_{2ax,2eq}$ 12.0, $J_{2ax,3}$ 11.5, $J_{2eq,3}$ 5.0, $J_{3,4}$ 10.0, $J_{4,5}$ 10.0, $J_{5,6a}$ 5.0, $J_{5,6b}$ 2.5 Hz; not assigned to the individual anomers: δ 10.96 (bs, 1 H, NH), 7.77, 7.60 (2 d, 1 H, H-4i), 7.35, 7.33 (2 d, 1 H, H-7i), 7.07 (t, 1 H, H-5i), 6.95 (m, 1 H, H-6i), 4.20–3.76 (m, 2 H, H-8a, H-8b), 2.07–1.92 (m, 12 H, 4 × OAc).

S-*(2,3,4-Tri-*O*-acetyl-6-deoxy-β-*D*-glucopyranosyl)* O-*(potassium sulfonato)indol-3-ylacetothiohydroximate (6-deoxy-glucobrassicin triacetate,* **39**).—To a cooled (0°C) and stirred solution of anhyd pyridine (1 mL) in anhyd CH_2Cl_2 (2 mL), a solution of chlorosulfonic acid (0.13 mL, 2.1 mmol) in CH_2Cl_2 (2 mL) was added slowly. After stirring for 10 min, **37** (305 mg, 0.64 mmol) in CH_2Cl_2 (1 mL) was added dropwise to the milky solution and stirred for 24 h under Ar. The mixture was neutralized with a

solution of $KHCO_3$ (200 mg, 2 mmol) in water (2.5 mL), stirred for 30 min, then extracted with CH_2Cl_2. The extract was dried over $MgSO_4$, concentrated under reduced pressure, and chromatographed on silica gel (9:1 CH_2Cl_2–MeOH) to afford **39** (86 mg, 69%); $[\alpha]_D^{20}$ +1° (*c* 1.0, MeOH); ^{1}H NMR (400 MHz, Me_2SO): δ 8.57 (d, 1 H, NH), 7.67 (d, 1 H, H-4i), 7.35 (d, 1 H, H-7i), 7.34 (s, 1 H, H-2i), 7.08 (dd, 1 H, H-6i), 6.96 (dd, 1 H, H-5i), 5.33 (d, 1 H, H-1), 5.10 (dd ~ t, 1 H, H-3), 4.77 (dd ~ t, 1 H, H-4), 4.62 (dd ~ t, 1 H, H-2), 4.03, 3.98 (2 d, 2 H, H-8a, H-8b, ^2J 16.0 Hz), 3.64 (dq, 1 H, H-5), 1.98, 1.91, 1.85 (3 s, each 3 H, 3 × OAc), 0.93 (d, 3 H, H-6); $J_{1,2}$ 9.5, $J_{2,3}$ 9.5, $J_{3,4}$ 9.5, $J_{4,5}$ 9.5, $J_{5,6}$ 6.0 Hz.

S-*(2-Deoxy-α,β-*D-arabino-*hexopyranosyl)* O-*(potassium sulfonato)indol-3-ylacetothiohydroximate (2-deoxy-glucobrassicin,* **40**).—Compound **38** was dissolved in anhyd MeOH (5 mL). A pH value of 8.0 was attained by addition of 0.8 M methanolic MeOK. After stirring for 3 h under Ar the product was isolated in the same way as **31**; **40** was obtained as a colourless solid (68 mg, 33%); ^{1}H NMR (300 MHz, Me_2SO): α-anomer: δ 5.94 (dd ~ d, 0.4 H, H-1), 3.85 (m, 0.4 H, H-3), 3.37 (dd ~ t, 0.4 H, H-4), 2.05 (m, 0.4 H, H-2eq), 1.92 (ddd, 0.4 H, H-2ax); $J_{1,2ax}$ 5.5, $J_{2ax,2eq}$ 14.0, $J_{2ax,3}$ 12.5, $J_{3,4}$ 10.0, $J_{4,5}$ 10.0 Hz; β-anomer: δ 5.06 (dd, 0.6 H, H-1), 3.75–3.55 (m, 1.2 H, H-6a, H-6b), 3.44 (ddd, 0.6 H, H-3), 3.37 (dd ~ t, 0.6 H, H-4), 3.12 (ddd, 0.6 H, H-5), 2.05, 1.60 (m, 1.2 H, H-2ax, H-2eq); $J_{1,2ax}$ 12.0, $J_{1,2eq}$ 2.0, $J_{2ax,3}$ 11.0, $J_{2eq,3}$ 5.0, $J_{3,4}$ 9.0, $J_{4,5}$ 9.0, $J_{5,6a}$ 4.5, $J_{5,6b}$ 2.0 Hz; not assigned to the individual anomers: δ 7.81, 7.80 (2 d, 1 H, H-4i), 7.58, 7.57 (2 d, 1 H, H-7i), 7.34–7.20 (m, 2 H, H-5i, H-6i), 4.40–3.70 (m, remaining sugar protons).

S-*(6-Deoxy-β-*D-*glucopyranosyl)* O-*(potassium sulfonato)indol-3-ylacetothiohydroximate (6-deoxy-glucobrassicin,* **41**).—Methanolic MeOK (0.8 M) was added to a stirred solution of **39** (100 mg, 167 μmol) in anhyd MeOH (4 mL) to give pH 8.0 and stirred for 30 min. The mixture was concentrated under reduced pressure, taken up in water, and purified on a Sep-Pak C-18 cartridge. Freeze-drying yielded **41** as a white powder (70 mg, 90%); $[\alpha]_D^{20}$ −2° (*c* 1.0, H_2O); ^{1}H NMR (400 MHz, D_2O): δ 7.67 (d, 1 H, H-4i), 7.45 (d, 1 H, H-7i), 7.25 (s, 1 H, H-2i), 7.19 (dd ~ t, 1 H, H-6i), 7.11 (dd ~ t, 1 H, H-5i), 4.73 (d, 1 H, H-1), 4.13 (s, 2 H, H-8a, H-8b), 3.17 (dd ~ t, 1 H, H-2), 3.06 (dd ~ t, 1 H, H-3), 2.91 (dd ~ t, 1 H, H-4), 2.68 (dq, 1 H, H-5), 0.87 (d, 3 H, H-6); $J_{1,2}$ 9.5, $J_{2,3}$ 9.5, $J_{3,4}$ 9.5, $J_{4,5}$ 9.5, $J_{5,6}$ 6.0 Hz.

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References

[1] H.L. Tookey, C.H. VanEtten, and M.E. Daxenbichler, in I.E. Liener (Ed.), *Toxic Constituents of Plant Foodstuffs*, Academic Press, New York, 1980, pp 103–142.

[2] G.R. Fenwick, R.K. Heaney, and W.J. Mullin, *CRC Critical Reviews in Food Science and Nutrition*, CRC Press, Boca Raton, Florida, 1983, pp 123–201.
[3] R. McDanell, A.E.M. McLean, A.B. Hanley, R.K. Heaney, and G.R. Fenwick, *Food Chem. Toxicol.*, 26 (1988) 59–70.
[4] M. Blanc-Muesser, H. Driguez, B. Joseph, M.-C. Viaud, and P. Rollin, *Tetrahedron Lett.*, 31 (1990) 3867.
[5] C. Gardrat, A. Quinsac, B. Joseph, and P. Rollin, *Heterocycles*, 35 (1993) 1015–1027.
[6] B. Joseph and P. Rollin, *J. Carbohydr. Chem.*, 12 (1993) 719–729.
[7] S. Lazar and P. Rollin, *Tetrahedron Lett.*, 35 (1994) 2173–2174.
[8] M. Černý, J. Staněk, and J. Pacák, *Monatsh. Chem.*, 94 (1963) 290–294.
[9] J. Thiem and B. Meyer, *Chem. Ber.*, 113 (1980) 3075–3085.
[10] J. Fuentes, M.A. Pradera, and I. Robina, *Tetrahedron*, 47 (1991) 5797–5810.
[11] A.J. Kirby, *The Anomeric Effect and Stereoelectronic Effects at Oxygen*, Springer, Berlin, 1983.
[12] H. Paulsen, *Angew. Chem., Int. Ed. Engl.*, 21 (1982) 155–173.
[13] G. Adiwidjaja, B. Meyer, H. Paulsen, and J. Thiem, *Tetrahedron*, 35 (1979) 373–384.
[14] R.U. Lemieux, *Methods Carbohydr. Chem.*, 2 (1963) 221–222.
[15] W. Schüep and E. Hardegger, *Helv. Chim. Acta*, 53 (1970) 1336–1339.
[16] V.N. Shibaev, Y.Y. Kusov, I.V. Komlev, E.I. Budovskii, and N.K. Kochetkov, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 11 (1969) 2522–2526; *Chem. Abstr.*, 72 (1970) 90804.
[17] B. Leon, S. Liemann, and W. Klaffke, *J. Carbohydr. Chem.*, 12 (1993) 597–610.
[18] M.H. Benn, *Can. J. Chem.*, 41 (1963) 2836–2838.
[19] M.-C. Viaud and P. Rollin, *Tetrahedron Lett.*, 31 (1990) 1417–1418.