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Exploring an Alternative Approach to the Synthesis of Arylalkyl and Indolylmethyl Glucosinolates

Stéphanie Cassel[b], Brigitte Casenave[a], Gérard Déléris[a], Laurent Latxague[a] and Patrick Rollin[b*]

[a] Laboratoire de Chimie Bio-Organique, Université Victor Segalen Bordeaux 2, 146 Rue Léo Saignat, F-33076 Bordeaux, France.
[b] Institut de Chimie Organique et Analytique, UPRES-A 6005, Université d'Orléans, B.P. 6759, F-45067 Orléans Cedex 2, France.

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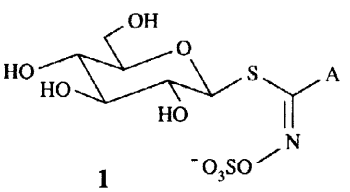
Abstract: A new approach to the elaboration of hydroximoyl chlorides - key-compounds in the synthesis of glucosinolates - based on nitrovinyl intermediates was explored in the case of arylalkyl conjugates and their indolylmethyl counterparts. © 1998 Elsevier Science Ltd. All rights reserved.

INTRODUCTION

Glucosinolates (GSLs) **1** are long-known phyto-molecules which have always been associated with a strong and highly diversified physiological impact in animals and plants.[1]



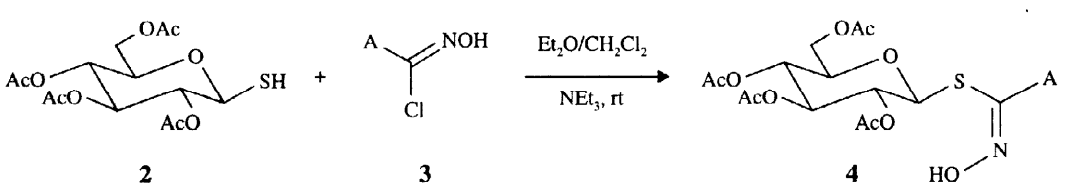
1

A = alkyl, alkenyl, arylalkyl, hydroxyalkenyl, indolylmethyl, thiofunctionalized

A limited number of pure GSLs can be isolated from crucifer vegetables through dedicated extractive and separative procedures, which prove tedious and problematical in some cases.[2]

In contrast, the synthetic approach opens more widely applicable routes to most naturally-occurring GSLs[3] and, moreover, it gives the only access to structurally-modified or totally artificial GSLs,[4] which are useful substrates in miscellaneous analytical[5] or biological[6] applications.

The synthetic pathways which have been developed for GSLs within recent decades are invariably based on a key coupling step between partially protected 1-thio-β-D-glucopyranose **2** and a highly reactive hydroximoyl chloride **3** to yield stereospecifically a *(Z)*-thiohydroximate precursor **4** :



2 **3** **4**

* Corresponding author : fax: +33 (0) 2 38 49 45 79 e-mail: patrick.rollin@univ-orleans.fr

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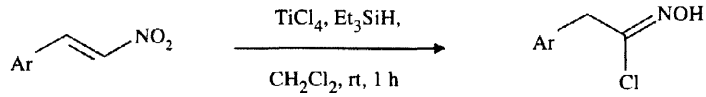
Hydroximoyl chlorides **3** can in turn be produced :

- either by direct chlorine[7] or N-chlorosuccinimide[8] chlorination of the corresponding aldoximes, in which case unwanted side-reactions such as substitutive chlorination of the A moiety cannot always be avoided.[9]

- or through transformation of a primary nitro-derivative RCH_2NO_2 into its nitronate anion, which in turn is reacted at low temperature with an electrophilic activator / Cl-donor, e.g. thionyl chloride.[10] The latter methodology is indeed better adapted for chlorination-sensitive or oxidation-prone substrates, but i) preparation of the nitro-derivative - commonly through chemoselective hydrogenation of a nitrovinyl precursor - is not always straightforward and ii) preparation and handling of alkaline nitronate salts can occasionally prove tricky.

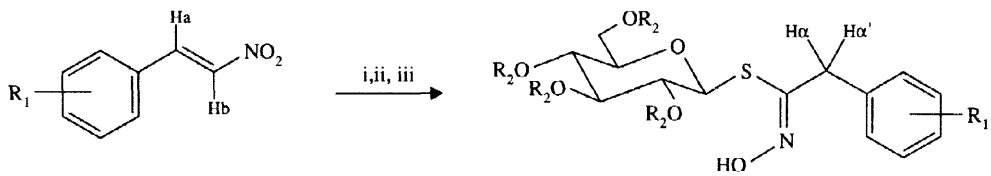
Lately, Kulkarni *et al.*[11] developed from nitrovinyl precursors **5** a new and direct access to arylalkyl hydroximoyl chlorides **6** :



5 **6**

RESULTS AND DISCUSSION

Our recent involvement in an analytical program aimed at the evaluation of the GSL content in white mustard (*Sinapis alba L.*) and related cruciferous adventices led us to perform the synthesis of desulfo-glucosinalbin **8a** for HPLC standardization. We therefore took this opportunity to investigate the applicability of the Kulkarni method. Hence *p*-hydroxy-(2-nitro)styrene **5a**[12] was treated with triethylsilane and $TiCl_4$ and the crude reaction product was subsequently reacted with thiosugar **2** in standard conditions.[4]



5a R_1 = *p*-OH
5b R_1 = *p*-OAc
5c R_1 = *p*-OMe
5d R_1 = *o*-OMe

7a, 8a R_1 = *p*-OH
7b R_1 = *p*-OAc
7c, 8c R_1 = *p*-OMe
7d, 8d R_1 = *o*-OMe

iv → **7a-d** R_2 = Ac; **8a-d** R_2 = H

i) $TiCl_4$, Et_3SiH, CH_2Cl_2, rt, 1 h. ii) aqueous work-up. iii) **2**, CH_2Cl_2/Et_2O, Et_3N, rt, 2 h. iv) MeOH/MeONa, rt, 24 h.

After purification of the reaction mixture, it appeared that the expected intermediate thiohydroximate **7a** was only obtained in very small amounts. It was inferred from this result that the presence of a free phenolic function was inconsistent with the Kulkarni reaction conditions, so we decided to try and react a protected form of **5a**. When using *p*-acetoxy-(2-nitro)styrene **5b**[12] as chlorine acceptor, the outcome was incomparably better - the thiohydroximate **7b**[13] being isolated in 82 % yield.

It was of course further expected[11] that the presence on the aromatic nucleus of alkoxy substituents would also allow the smooth transformation into hydroximoyl chlorides **6** and consequently the preparation of compounds **7**. This was demonstrated in the case of *p*- and *o*-methoxy-(2-nitro)styrenes **5c** and **5d**,[12] which led to thiohydroximates **7c**[13] and **7d** in 84 and 50 % yield, respectively. Standard deacetylation of **7b**, **7c** and **7d** in a basic medium afforded respectively desulfo-glucosinalbin **8a**, desulfo-glucoaubrietin **8c** and its artificial regioisomer **8d**. Compounds **8a** and **8c** could be used quite satisfactorily as HPLC calibrants for the analysis of miscellaneous samples of *Sinapis alba L.* and *Aubrietia sp.*

This work demonstrates that synthesizing substituted glucotropaeolins and other arylalkyl glucosinolates can be envisaged via an alternative route, skipping the cumbersome intermediates of the previously reported methods.[7,10]

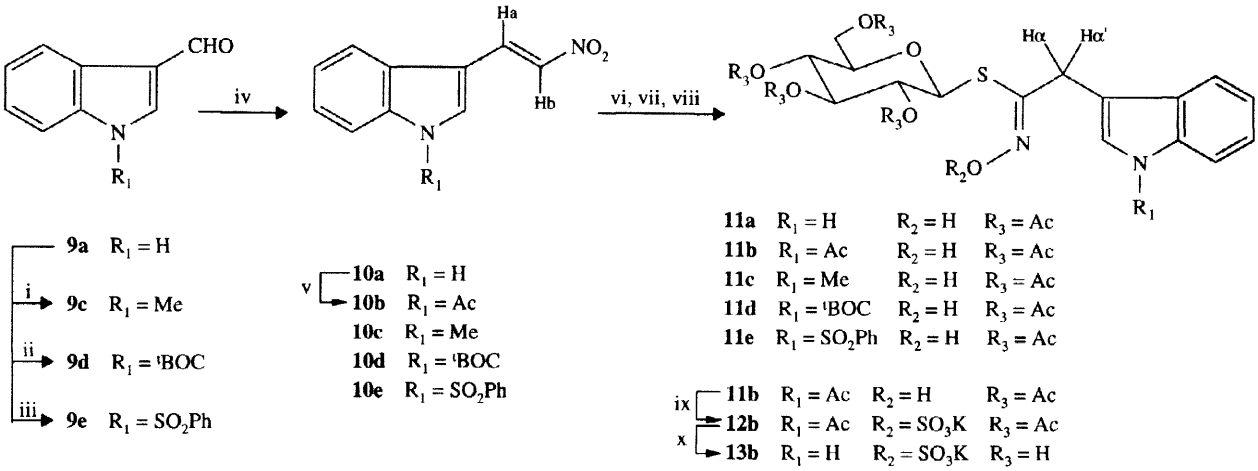
Extension of the Kulkarni-type approach to the synthesis of other families of GSLs would of course be of prime interest. The glucobrassicins (3-indolylmethyl GSLs) constitute a particularly attractive family because of their marked physiological effects in animals and man.[14]

It became clear from the foregoing results that the indole precursor for the Kulkarni reaction should be N-protected, so the readily available 3-(2-nitrovinyl)indole **10a**[15] was transformed in 88% yield into the known N-acetyl-3-(2-nitrovinyl)indole **10b**,[16] which was then reacted with $TiCl_4$ and triethylsilane. The crude intermediate hydroximoyl chloride produced was used without further purification in the coupling step to afford the glycosyl thiohydroximate **11b** in 35% yield - a decent outcome for indole GSL.

The *O*-sulfation of **11b** followed by deprotection of glucobrassicin peracetate **12b** gave glucobrassicin **13b** in 55 % yield.

As in the case of arylalkyl GSLs, this alternative approach competes favourably with our previously published procedure :[3a] the transformation of the nitrovinyl precursor **10a** into the key-compound **11b** is appreciably shorter and spares tedious handling of an alkaline nitronate.

Nevertheless, in order to try and evaluate the influence of the N-protecting group on the outcome of the coupling step affording the thiohydroximate, three other nitrovinyl precursors were prepared : N-methyl-3-(2-nitrovinyl)indole **10c**,[15] N-(*t*-butoxycarbonyl)-3-(2-nitrovinyl)indole **10d** and N-(phenylsulfonyl)-3-(2-nitrovinyl)indole **10e**. Treatment of **10c** in the Kulkarni conditions, followed by coupling with thio-sugar **2** led to thiohydroximate **11c** in 76 % yield; the yield of the same transformation in three steps - via the nitronate - never exceeded 24 %. The same reaction conditions applied to **10d** afforded no coupled product whereas the N-sulfonylated nitrovinyl derivative **10e** could be transformed into the thiohydroximate **11e** with a 55 % coupling yield.



i) CH_3CN, MeI, K_2CO_3, reflux, 6 h. ii) CH_2Cl_2, BOC_2O, Et_3N, rt, 24 h. iii) NaH, THF, $PhSO_2Cl$, rt, 3 h.
iv) CH_3NO_2, ammonium acetate, reflux, 2 h. v) Ac_2O, DMAP. vi) $TiCl_4$, Et_3SiH, CH_2Cl_2, rt, 1 h. vii) aqueous work-up.
viii) **2**, CH_2Cl_2/Et_2O, Et_3N, rt, 2 h. ix) HSO_3Cl, pyridine, 0°C. x) MeOK, MeOH.

It is thus made clear in the indole series that the N-substitution is critical with regard to the Kulkarni-modified coupling step. The case of **10d** is atypical because of the particular Lewis acid-sensitivity of the *t*-BOC group, resulting in ill-timed deprotection of the indole nitrogen.

Conclusion

In the expanding field of glucosinolates (GSLs), extractive and synthetic approaches are complementary. Because of growing applications of natural and artificial GSLs, improved chemical synthesis methodologies are constantly required in order to reduce the length and discomfort of the sequences.

The applicability of a shortened and simple pathway was fully demonstrated in the case of two important structural families : the arylalkyl GSLs and the indolylmethyl GSLs. Further improvements of the synthetic pathways to other GSL types are currently under investigation in our laboratory.

Experimental part

Melting points were determined on a Kofler hot stage apparatus and are uncorrected. NMR spectra were recorded in $CDCl_3$ (unless otherwise stated) at 298K on Bruker DPX 250 or AM 300 spectrometers. Chemical shifts are expressed in parts per million downfield from TMS. In the presentation of NMR data, Hi refers to the indole moiety. Optical rotations were measured at 20°C with a Jobin-Yvon type 71 digital or a Perkin-Elmer 141 polarimeter. Thin layer chromatography was performed on aluminum plates precoated with Merck silica gel 60 F_{254}. Column chromatography was performed using silica gel 60 (70-230 mesh, Merck, Germany), and flash chromatography using silica gel 60 (230-400 mesh, SDS, France). Commercially available chemicals were used without further purification. Thiosugar **2** [19879-84-6] is commercially available.

The substituted *E*-nitrostyrenes **5a**, **5b**, **5c** and **5d** were produced according to the procedure described by Lappin[17] and recrystallised from ethanol.

p-Hydroxy-(2-nitro)styrene (5a) :

Yellow crystals (52 %) ; mp 168-169°C ; ^{1}H NMR : d 7.98 (d, 1H, H-a), 7.52 (d, 1H, H-b, $J_{H\text{-}a,H\text{-}b}$=13.8 Hz), 7.48(d, 2H, H-2, H-6), 6.91 (d, 2H, H-3, H-5), 5.44 (s, 1H, OH).

p-Acetoxy-(2-nitro)styrene (5b) :

Yellow crystals (88 %) ; mp 160-161°C ; ^{1}H NMR : d 8.00 (d, 1H, H-a), 7.58 (d, 2H, H-2, H-6), 7.56 (d, 1H, H-b, $J_{H\text{-}a,H\text{-}b}$=13.7 Hz), 7.23 (d, 2H, H-3, H-5), 2.34 (s, 3H, OAc).

p-Methoxy-(2-nitro)styrene (5c) :

Yellow crystals (35 %) ; mp 86-87°C ; ^{1}H NMR : d 7.98 (d, 1H, H-a), 7.52 (d, 1H, H-b, $J_{H\text{-}a,H\text{-}b}$=13.6 Hz), 7.51 (d, 2H, H-2, H-6), 6.97 (d, 2H, H-3, H-5), 3.88 (s, 3H, OCH_3).

o-Methoxy-(2-nitro)styrene (5d) :

Bright yellow oil (25 %) that crystallised at low temperature ; mp <50°C ; ^{1}H NMR : d 8.15 (d, 1H, H-a), 7.89 (d, 1H, H-b, $J_{H\text{-}a,H\text{-}b}$=13.6 Hz), 7.46 (d, 1H, H-6), 6.92-7.06 (m, 3H, H-3, H-4, H-5), 3.96 (s, 3H, OCH_3).

N-Methyl-3-formyl indole (9c) was prepared according to ref.[15]

Yellow-green crystals (95 %) ; mp 68-70°C ; ^{1}H NMR : d 9.87 (s, 1H, CHO), 8.22-8.27 (m, 1H, H-4i), 7.53 (s, 1H, H-2i), 7.25-7.29 (m, 3H, H-5i, H-6i, H-7i), 3.74 (s, 3H, NMe).

N-t-Butyloxycarbonyl-3-formyl indole (9d) was prepared according to ref.[18]

Colourless crystals (100 %) ; mp 124-126°C ; ^{1}H NMR : d 10.07 (s, 1H, CHO), 8.28 (d, 1H, $J_{H\text{-}4i,H\text{-}5i}$ = 7.6 Hz, H-4i), 8.24 (s, 1H, H-2i), 8.14 (d, 1H, $J_{H\text{-}7i,H\text{-}6i}$ = 7.6 Hz, H-7i), 7.41 (dd, 1H, H-6i), 7.36 (dd, 1H, H-5i), 1.70 (s, 9H, Me_3C). Anal. calcd for $C_{14}H_{15}NO_3$: C, 68.55; H, 6.16; N, 5.71. Found : C, 68.49; H, 6.09; N, 5.58.

N-Phenylsulfonyl-3-formyl indole (9e) was prepared according to ref.[19]

Light brown crystals (89 %) ; mp 155-157°C ; ^{1}H NMR : d 10.12 (s, 1H, CHO), 8.26 (m, 1H, H-4i), 8.01-7.91, 7.72-7.34 (m, 9H, H-2i, H-5i, H-6i, H-7i + $\underline{Ph}SO_2$).

The substituted *E*-nitrovinylindoles **10a** and **10c** were produced according to the procedure described by Canoira.[15]

1-*H*-3-(2-Nitrovinyl)indole (10a) :

(65 %) ; mp 169-172°C ; ^{1}H NMR : d 8.30 (d, 1H, , H-a, $J_{H\text{-}a,\,H\text{-}b}$=13.6 Hz), 7.80 (d, 1H, H-b), 7.78 (d, 1H, H-4i), 7.67 (d, 1H, $J_{H\text{-}2i,\,NH}$=3.0 Hz, H-2i), 7.48 (m, 1H, H-7i), 7.34 (m, 2H, H-5i, H-6i,).

N-Acetyl-3-(2-nitrovinyl)indole (10b) was produced by acetylation of **10a :**

(88 %) ; mp 165-167°C ; ^{1}H NMR : d 8.18 (d, 1H, H-a, $J_{H\text{-}a,\,H\text{-}b}$=13.4 Hz), 7.87 (s, 1H, H-2i), 7.81 (d, 1H, H-b), 7.41-7.52 (m, 2H, H-5i, H-6i), 7.28 (d, 1H, H-7i), 2.72 (s, 3H, $COCH_3$).

N-Methyl-3-(2-nitrovinyl)indole (10c) :

Yellow crystals (recrystallised from methanol) (83 %) ; mp 170-172°C ; ^{1}H NMR : d 8.25 (d, 1H, H-a, $J_{H\text{-}a,\,H\text{-}b}$=13.4 Hz), 7.76 (d, 1H, H-b), 7.75 (d, 1H, H-4i), 7.52 (s, 1H, H-2i), 7.40-7.30 (m, 3H, H-5i, H-6i, H-7i), 3.88 (s, 3H, NMe).

N-*t*-Butyloxycarbonyl-3-(2-nitrovinyl)indole (10d) :

A suspension of the N-protected aldehyde (1.0 g, 4.1 mmol) and ammonium acetate (1.1 eq.) in nitromethane (10 mL) was stirred under reflux for 2 hours, then the mixture was allowed to cool. The solvent was evaporated under reduced pressure and the residue was recrystallised from methanol (541 mg, 46 %) ; mp 144-146°C ; ^{1}H NMR : d 8.20 (d, 1H, H-a, $J_{H\text{-}a,\,H\text{-}b}$=13.6 Hz), 8.06 (s, 1H, H-2i), 7.81 (d, 1H, H-b), 7.73-7.77 (m, 1H, H-4i), 7.38-7.50 (m, 3H, H-5i, H-6i, H-7i), 1.72 (s, 9H, Me_3C). Anal. calcd for $C_{15}H_{16}N_2O_4$: C, 62.49; H, 5.59; N, 9.72. Found : C, 62.41; H, 5.43; N, 9.50.

N-Phenylsulfonyl-3-(2-nitrovinyl)indole (10e) :

A suspension of the N-protected aldehyde (1.5 g, 5.3 mmol) and ammonium acetate (1.1 eq.) in nitromethane (10 mL) was stirred under reflux for 2 hours, then the mixture was allowed to cool. The solvent was evaporated under reduced pressure and the residue was purified by flash chromatography on silica gel (eluent petroleum ether/ethyl acetate 7:3) to yield yellow crystals which were recrystallised from methanol (508 mg, 44 %) ; mp 207-209°C ; ^{1}H NMR : d 8.16 (d, 1H, H-a, $J_{H\text{-}a,\,H\text{-}b}$=13.7 Hz), 7.37-8.07 (m, 11H, H-b, H-2i, H-4i, H-5i, H-6i, H-7i + $\underline{Ph}SO_2$). Anal. calcd for $C_{16}H_{12}N_2O_4S$: C, 58.53; H, 3.68; N, 8.53. Found : C, 58.62; H, 3.71; N, 8.41.

General procedure for the synthesis of thiohydroximates 7a-d and 11a-e :

To a stirred solution of the primary nitro-derivative (2 eq.) in CH_2Cl_2 (10 mL/mmol) under argon Et_3SiH (2.2 eq.) was added. The solution was cooled in an ice bath and $TiCl_4$ (2.4 eq.) was added dropwise. The mixture was stirred under argon for one hour, then poured on ice and extracted three times with CH_2Cl_2. The organic layer was washed with water, dried over $MgSO_4$, filtered and the filtrate was concentrated under reduced pressure. The residue was dried under high vacuum and the crude product obtained was dissolved in a 2:1 mixture of dry Et_2O/CH_2Cl_2 (18 mL/mmol). 2,3,4,6 Tetra-*O*-acetyl-1-thio-b-D-glucopyranose (1 eq.) dissolved in CH_2Cl_2 was added and the resulting mixture was treated with Et_3N (6 eq.) diluted in anhydrous ether. The solution was stirred for 2 hours at room temperature under argon, then acidified with an aqueous 0.7 N solution of H_2SO_4 (20 mL/mmol of sugar). The mixture was stirred for about 10 minutes and separated. The aqueous phase was extracted twice with CH_2Cl_2, dried over $MgSO_4$, filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by flash chromatography on silica gel (eluent CH_2Cl_2/MeOH 1 to 3 %) to yield the pure thiohydroximate.

Glucosinalbin thiohydroximate (7a) :

Yellowish oil (<10 %, contaminated material).

***p*-*O*-Acetyl glucosinalbin thiohydroximate (7b) :**

Brownish foam (82 %) ; $[a]_D$ = - 8 (*c* 1.0, $CHCl_3$).

Glucoaubrietin thiohydroximate (7c) :

Colourless crystals (84 %) ; mp 152-154°C ; $[a]_D$ = - 1 (*c* 1.0, $CHCl_3$).

***o*-Methoxy glucotropaeolin thiohydroximate (7d) :**

Colourless foam (50 %) ; $[a]_D$ = + 11 (*c* 1.0, $CHCl_3$). Anal. calcd for $C_{23}H_{29}NO_{11}S$: C, 52.36; H, 5.54; N, 2.66. Found : C, 52.12; H, 5.32; N, 2.47.

d (ppm) *J* (Hz)	H_1 $J_{1,2}$	H_2 $J_{2,3}$	H_3 $J_{3,4}$	H_4 $J_{4,5}$	H_5 $J_{5,6a}$	H_{6a} $J_{6a,6b}$	H_{6b} $J_{5,6b}$	OAc	NOH	Hα,α'	H_{Ar}	R_1
7a	d 4.85 *9.7*	m 4.94 - 5.13			m 3.52 *5.5*	dd 4.15 *12.3*	dd 4.05 *2.5*	s 2.10 s 2.03 s 1.99	7.98	s 3.89	d 7.14 d 6.83	s 5.35
7b	d 4.85 *9.7*	m 4.95 - 5.14			m 3.52 *5.5*	dd 4.17 *12.4*	dd 4.03 *2.4*	s 2.08, s 2.02 s 1.99, s 1.98	7.83	s 3.94	d 7.29 d 7.10	s 2.31
7c	d 4.83 *9.6*	m 4.97 - 5.07			m 3.54 *5.7*	dd 4.16 *12.5*	dd 4.05 *2.5*	s 2.09 s 2.02 s 1.97	8.00	s 3.90	d 7.18 d 6.90	s 3.83
7d	d 4.84 *9.5*	m 4.95 - 5.09			m 3.55 *5.4*	dd 4.17 *12.5*	dd 4.07 *2.3*	s 2.09, s 2.02 s 1.99, s 1.94	7.87	d 4.05 d 3.78 *J*a,a'=16.7	7.32, 7.23 6.98, 6.92	s 3.90

Table 1 : *NMR data for thiohydroximates* ***7a-d.***

N-Acetyl glucobrassicin thiohydroximate (11b) :

White solid (35%) ; mp 203°C ; $[a]_D$ = -10 (*c* 1.0, $CHCl_3$) . Anal. calcd for $C_{26}H_{30}N_2O_{11}S$: C, 53.97; H, 5.23; N, 4.84. Found : C, 53.80; H, 5.09; N, 4.71.

N-Methyl glucobrassicin thiohydroximate (11c) :

Brownish oil (76 %) ; $[a]_D$ = - 9 (*c* 1.0, $CHCl_3$). Anal. calcd for $C_{25}H_{30}N_2O_{10}S$: C, 54.53; H, 5.49; N, 5.09. Found : C, 54.58; H, 5.39; N, 4.97.

N-Phenylsulfonyl glucobrassicin thiohydroximate (11e) :

Yellowish oil (55 %) ; $[a]_D$ = - 10 (*c* 1.0, $CHCl_3$). Anal. calcd for $C_{30}H_{32}N_2O_{12}S_2$: C, 53.24; H, 4.77; N, 4.14. Found : C, 53.09; H, 4.70; N, 3.98.

d (ppm) *J* (Hz)	H_1 $J_{1,2}$	H_2 $J_{2,3}$	H_3 $J_{3,4}$	H_4 $J_{4,5}$	H_5 $J_{5,6a}$	H_{6a} $J_{6a,6b}$	H_{6b} $J_{5,6b}$	OAc	NOH	Hα,α'	Hi	R_1
11b	m 4.95 - 5.10				m 3.45	m 3.95 - 4.15		s 1.99 s 1.96 s 1.95	-	s 4.05	H_4 8.41 H_2, H_5, H_6, H_7 m 7.23-7.52	s 2.60
11c	m 4.97 - 5.04				m 3.29 *4.9*	dd 4.08 *12.4*	dd 3.92 *2.3*	s 2.07 s 1.99 s 1.97	8.00	s 4.03	H_4 7.59 H_7 7.33 H_6 7.28 H_5 7.15 H_2 6.97	s 3.79
11e	m 4.92 - 5.09				m 3.50 *5.7*	dd 4.16 *12.4*	dd 4.05 *2.4*	s 2.05 s 2.02 s 2.00	8.33	s 3.96	H_4 7.99 H_7 H_6 7.87-7.91 H_2 7.76	m 7.46-7.59

Table 2 : *NMR data for thiohydroximates* ***11b, 11c*** *and* ***11e.***

General procedure for the deacetylation of thiohydroximates 7b, 7c and 7d :

The thiohydroximate was deacetylated by a catalytic amount of MeONa in dry MeOH overnight at room temperature. The basic solution was neutralised by addition of acidic ion-exchange resin (Amberlite® IR 120, H^+). The resin was removed by filtration and the neutral methanolic solution was evaporated under reduced pressure. The residue was purified by flash chromatography on silica gel (eluent CH_2Cl_2/MeOH 10 to 20 %) to yield the pure desulfoglucosinolate **8a**, **8c** or **8d**.

Desulfoglucosinalbin (8a) :

Colourless amorphous powder ; $[a]_D$ = -26 (*c* 0.45, MeOH) ; ^{1}H NMR (D_2O). Anal. calcd for $C_{14}H_{19}NO_7S$: C, 48.69; H, 5.55; N, 4.06. Found : C, 48.81; H, 5.40; N, 3.94.

Desulfoglucoaubrietin (8c) :

Colourless amorphous powder ; $[a]_D$ = -36 (*c* 0.3, MeOH) ; ^{1}H NMR (D_2O). Anal. calcd for $C_{15}H_{21}NO_7S$: C, 50.13; H, 5.89; N, 3.90. Found : C, 49.97; H, 5.95; N, 3.76.

***o*-Methoxy desulfoglucotropaeolin (8d) :**

Colourless crystalline solid (91 %) ; mp 106-108°C ; $[a]_D$ = 0 (*c* 1.0, H_2O) ; ^{1}H NMR (D_2O). Anal. calcd for $C_{15}H_{21}NO_7S$: C, 50.13; H, 5.89; N, 3.90. Found : C, 50.03; H, 5.99; N, 3.72.

d (ppm) *J* (Hz)	H_1 $J_{1,2}$	H_2 $J_{2,3}$	H_3 $J_{3,4}$	H_4 $J_{4,5}$	H_5 $J_{5,6a}$	H_{6a} $J_{6a,6b}$	H_{6b} $J_{5,6b}$	Ha,a'	H_{Ar}	OMe
8a	m 4.75 *9.3*	3.34	3.44	3.37	m 3.26 *2.5*	dd 3.71 *12.6*	dd 3.68 *4.8*	d 4.00, d 3.97 *Ja,a'*= 16.6	d 7.25 d 6.94	-
8c	m 4.74 *9.4*	dd 3.35 *9.6*	dd 3.44 *9.6*	dd 3.37 *9.6*	m 3.27 *2.5*	dd 3.71 *12.5*	dd 3.67 *4.8*	s 4.01	d 7.32 d 7.05	-
8d	m 4.78 *10.0*	3.39	m 3.46 - 3.50		m 3.30 *2.5*	dd 3.77 *13.0*	dd 3.72 *5.0*	d 4.12, d 3.93 *Ja,a'*= 16.6	m 7.42-7.08	s 3.93

Table 3 : *NMR data for desulfo-GSL 8a, 8c and 8d.*

N-Acetyl proglucobracissin (12b) :

To a cooled (0°C) and stirred solution of thiohydroximate **11b** (200 mg, 0.34 mmol) in dry pyridine (2.5 mL) and dry dichloromethane (1.25 mL) under inert atmosphere, a solution of chlorosulfonic acid (0.43 g, 3.7 mmol) in dry diethylether (1.25 mL) was added over a period of 40 min. The resulting mixture was stirred for 24 h at room temperature, hydrolyzed with a $KHCO_3$ solution (0.2 g) in water (2.5 mL), stirred another 30 min, and extracted with chloroform. The combined extracts were dried ($MgSO_4$), filtered and evaporated under reduced pressure. Flash-chromatography (CH_3OH 5% in dichloromethane) yielded **12b** as a white solid (150 mg, 62%) ; mp 162°C (dec.) ; $[a]_D$ = -4 (*c* 1.0, MeOH) ; ^{1}H NMR (DMSO-d_6) : d 8.29 (d, 1H, H-4i, *J* = 7.4 Hz), 7.87 (s, 1H, H-2i), 7.70 (d, 1H, H-7i, *J* = 7.4 Hz), 7.32 (dd, 1H, H-6i, *J* = 7.4 Hz), 7.23 (dd, 1H, H-5i, *J* = 7.4 Hz), 5.55 (d, 1H, H-1, $J_{1,2}$ = 9.5 Hz), 5.36 (dd, 1H, H-3, $J_{3,4}$ = 9.5 Hz), 4.90 (dd, 1H, H-4, $J_{4,5}$ = 9.5 Hz), 4.82 (dd, 1H, H-2, $J_{2,3}$ = 9.5 Hz), 3.89-4.10 (m, 5H, H-5, H-6a, H-6b,Ha,a'), 2.62 (s, 3H, N-Ac), 1.82, 1.88, 1.91, 1.95 (4s, 12H, OAc).

Glucobrassicin (13b) :

To a stirred solution of compound **12b** (400 mg, 0.6 mmol) in anhydrous methanol (25 mL) under inert atmosphere a few drops of potassium methoxide (1N solution) were added until pH 8. After stirring for 12 h at room temperature, the solution was made neutral by the addition of glacial acetic acid, then concentrated under reduce pressure. The resulting brown solid was dissolved in water (5 mL), purified on Sep-Pak C-18 cartridges (Waters) and subjected to freeze-drying to yield **13b** as a white solid (260 mg, 89%) ; ^{1}H NMR (D_2O) and physical data were in agreement with previously reported data.[3a]

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