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Methyl D-*arabino*-hex-2-ulopyranosonate as a building block for spiro[1,4-benzoxazine-2,2′-pyrans]☆

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Abstract

A novel glycosyl donor, methyl (3,4,5-tri-*O*-acetyl-β-D-*arabino*-hex-2-ulopyranosyl)onate bromide, obtained in two steps from methyl β-D-*arabino*-hex-2-ulopyranosonate, was converted into its α-nitrophenyl glycoside, which in turn was reductively cyclized to form acetylated benzoxazinoid spirans. Deprotection led to (2*S*)-3′,4,4′,5′-tetrahydroxy-D-*arabino*-2*H*-1,4-benzoxazin-2-spiro-2′-pyran-3(4*H*)-one and (2*S*)-3′,4′,5′-trihydroxy-D-*arabino*-2*H*-1,4-benzoxazin-2-spiro-2′-pyran-3(4*H*)-one. Analogous compounds are prepared from 5-methoxy-2-nitrophenol. The new class of spiro functionalized carbohydrates is structurally related to natural benzoxazinone acetal glucosides. The assignment of configuration and conformation of all products was based on ^{1}H NMR H,H coupling constants and optical rotation values.

Keywords: D-*arabino*-Hex-2-ulopyranosonates; Glycosidation; Spiro[1,4-benzoxazine-2,2′-pyran]ones; Cyclic hydroxamic acid

1. Introduction

Carbohydrates have often been used as inexpensive chiral building blocks for syntheses of various natural compounds, their analogues or precursors [1,2]. However, D-*arabino*-hex-2-ulosonic acid ('2-oxo-D-gluconic acid'), used on an industrial scale for the production of isoascorbic acid [3], has received little attention with regard to the synthesis of *O*- or *C*-glycosides [4] or as an α-keto carboxylate building block [5]. This acid has been synthesized by biochemical oxidation of D-glucose [6–8] or chemically from D-fructose derivatives using different oxidants [8]. A suitable starting material for chemical synthesis is the crystalline methyl β-D-*arabino*-hex-2-ulopyranosonate (**1**) [8]. The β-D-pyranose conformation of crystalline **1** undergoes a slow isomerization in solution to form an α-D-pyranoid as well as cis- and trans-furanoid isomers in addition to the β-D-pyranoid form [9].

Recently, we reviewed the synthesis of benzoxazinoids [10], naturally occurring in different species of *Gramineae* [11], *Acanthaceae* [12], *Ranunculaceae* [13], and *Scrophulariaceae* [14]. We reported on the diastereoselective synthesis of benzoxazinone acetal glucosides [15] and on the first synthesis of an enantiomer of a natural acetal glucoside [16]. The spiroacetalic saccharide–heterocycle combination reported resembles the acetal glucosides, structurally.

We describe here the preparation of a novel glycosyl donor, methyl (3,4,5-tri-*O*-acetyl-β-D-*arabino*-hex-2-ulopyranosyl)onate bromide, from methyl β-D-*arabino*-hex-2-ulopyran-

☆ Dedicated to Professor Klaus Schulze on the occasion of his 65th birthday.

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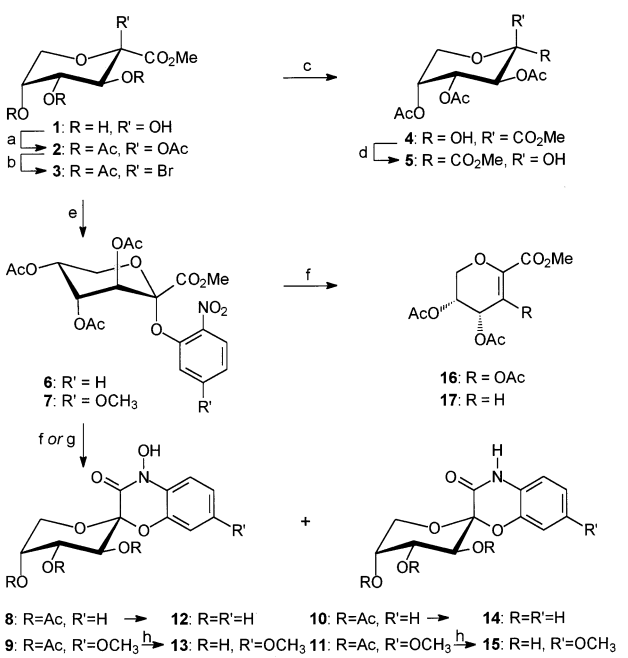
osonate and its glycosidation with 2-nitrophenol and 5-methoxy-2-nitrophenol, respectively, followed by reductive cyclization of the glycosides to novel benzoxazinoid spiro acetals (Scheme 1).

2. Results and discussion

On reinvestigating the acetylation of methyl β-D-*arabino*-hex-2-ulopyranosonate (**1**) with acetic anhydride [17,18] we have found that this reaction, in the presence of an acidic (H_2SO_4, $HClO_4$, $ZnCl_2$) or basic (4-DMAP in pyridine) catalyst, led to methyl 2,3,4,5-tetra-*O*-acetyl-β-D-*arabino*-hex-2-ulopyranosonate (**2**) as the main product (78%). On the contrary, performing the reaction in pyridine at 0 °C led to an inseparable mixture of tetraacetate **2** with trans- and cis-furanoid tetraacetates (88%, 1:12:2).

Bromination of **2** by hydrogen bromide generated in situ from phosphorus tribromide and water afforded a mixture of the methyl (3,4,5-tri-*O*-acetyl-β-D-*arabino*-hex-2-ulopyranosyl)onate bromide (**3**) accompanied by methyl 3,4,5-tri-*O*-acetyl-β-D-*arabino*-hex-2-ulopyranosonate (**5**) as the product of partial hydrolysis. Glycosyl bromide **3** was nearly quantitatively obtained when the reaction was performed with a solution of 33% hydrogen bromide in glacial acetic acid. Hydrolysis of **3** with silver carbonate and water yielded the stereoisomeric methyl 3,4,5-tri-*O*-acetyl-α-D-*arabino*-hex-2-ulopyranosonate (**4**), exclusively. On standing in chloroform solution for some days, the α isomer **4** underwent a complete isomerization into the thermodynamically stable β isomer **5**.



Scheme 1. (a) Ac_2O, H_2SO_4, 60 °C, 20 min; (b) HBr, HOAc; (c) Ag_2CO_3, H_2O; (d) $CHCl_3$, rt, 20 days; (e) 2-nitrophenol for **6**, 5-methoxy-2-nitrophenol for **7**, K_2CO_3, acetone, reflux; (f) NH_4Cl, Zn, MeOH, 2 h; (g) H_2, 5% Pt–C, MeOH; (h) 1. NaOMe, MeOH, 2. Amberlite IR 120.

Bromide **3** was used as a glycosyl donor in the reaction with potassium 2-nitro-phenolate or its 5-methoxy derivative in acetone. Due to the neighbouring group assistance of the 3-acetyl group, this reaction proceeds with inversion of the configuration at the anomeric centre via an intermediate acetyl oxonium ion, in which the axial position is shielded. Therefore, a nucleophile can only attack from the equatorial direction, which leads to an inversion at the anomeric centre. Diastereoselectively, methyl (2-nitrophenyl 3,4,5-tri-*O*-acetyl-α-D-*arabino*-hex-2-ulopyranosid)onate (**6**) and methyl (5-methoxy-2-nitrophenyl 3,4,5-tri-*O*-acetyl-α-D-*arabino*-hex-2-ulopyranosid)-onate (**7**) have been obtained as 2,3-trans nitrophenyl glycosides in yields of 96 and 47%, respectively. 5 - Methoxy - 2 - nitrophenolate proved to be a weak nucleophile preventing a complete reaction of **3** to **7**. Prolongation of the reaction time led to decomposition of **7** and **3**, only. However, parts of **3** could be recovered.

The nitrophenyl glycosides **6** and **7** are suitable precursors for reductive cyclizations to form a new class of carbohydrates with the spiro[1,4-benzoxazine-2,2′-pyrane]-skeleton. In principle both products with a cyclic hydroxamic acid and a lactam unit are to be expected, depending on whether the hydroxylamine or amine intermediate generated by reduction of the nitro group reacts with the ester group to form the benzoxazinone ring. Which cyclization is favoured can be controlled by the use of an appropriate reducing system. We have investigated the catalytic hydrogenation with different catalysts and solvents and the zinc dust reduction. Catalytic hydrogenation of the nitrophenyl glycosides **6**

and **7** in methanol over platinum on carbon at normal pressure gave rise to the lactams (2*S*)-3′,4′,5′-tri-*O*-acetyl-D-*arabino*-2*H*-1,4-benzoxazin-2-spiro-2′-pyran-3(4*H*)-one (**10**) (72%) and (2*S*)-3′,4′,5′-tri-*O*-acetyl-7-methoxy-D-*arabino*-2*H*-1,4-benzoxazin-2-spiro-2′-pyran-3(4*H*)-one (**11**) (95%), respectively. The cyclic hydroxamic acids (2*S*)-3′,4′,5′-tri-*O*-acetyl-D-*arabino*-4-hydroxy-2*H*-1,4-benzoxazin-2-spiro-2′-pyran-3(4*H*)-one (**8**) (23%) and (2*S*)-3′,4′,5′-tri-*O*-acetyl-D-*arabino*-4-hydroxy-7-methoxy-2*H*-1,4-benzoxazin-2-spiro-2′-pyran-3(4*H*)-one (**9**) (traces) were obtained as by-products. However, due to their ability to complex metal ions, cyclic hydroxamic acids are of special interest. Therefore attempts to increase the yields of **8** and **9** have been made. Variations of the hydrogenation system that have been successful in related cases, like using a deactivated catalyst (sulfided platinum on carbon) and an acidic solvent (glacial acetic acid) [19], have been of no avail in these cases. Hydrogenations in basic solvents are unusual but not impossible. Thus, interesting results were obtained on hydrogenation with the Pt–C catalyst in pyridine, which slows down the reduction of the hydroxylamine intermediate and enhances its nucleophilicity. Hydrogenation of **6** afforded 79% hydroxamic acid **8** as the major product and 15% lactam **10**. Glycoside **7** yielded hydroxamic acid **9** (39%) beside lactam **11** (49%). Finally, a standard reduction with zinc and ammonium chloride in methanol was performed directed on hydroxamic acids. Thus, reductive cyclization of **6** led to **8** (85%) accompanied by **10** (8%). Similarly, cyclization of **7** yielded **9** (54%) together with **11** (14%). Standard deprotection of the acetates **8**–**11** with methanolate followed by neutralization with an ion-exchange resin gave rise to the (2*S*)-3′,4′,5′-trihydroxy-D-*arabino*-2*H*-1,4-benzoxazin-2-spiro-2′-pyran-3(4*H*)-ones **12**–**15** in very good yield.

During the zinc dust reductions of the glycosides **6** and **7**, the formation of the glycals was observed as result of elimination side reactions. Thus, methyl 3,4,5-tri-*O*-acetyl-D-*erythro*-hex-2-enopyranosonate (**16**) (2%) was obtained from **6** and methyl 4,5-di-*O*-acetyl-2,6-anhydro-3-deoxy-D-*erythro*-hex-2-enosonate (**17**) (9%) was derived from **7**. Glycal **17** has been accessible in very good yield from glycosyl bromide **3** adapting a zinc dust/pyridine protocol in hot toluene used for the synthesis of 2,6-anhydro-3-deoxy-hex-2-enone nitriles [20].

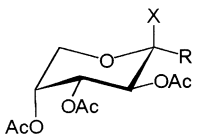
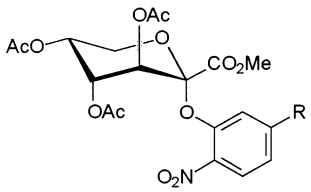
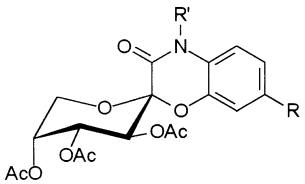
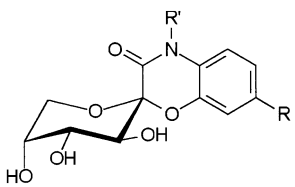
Some alternative reactions of glycosyl bromide **3** have been studied. In principle, lactam **10** (21%) can be alternatively synthesized by condensation of bromide **3** with 2-aminophenol in the presence of potassium carbonate. In this case, deprotonation of the ambident 2-aminophenol results in the necessary 2-aminophenyl *O*-glycosidic intermediate. However, this reaction is accompanied by a lot of decomposition products. Therefore, the reductive cyclization of the isolated 2-nitrophenyl glycosides is the preferred pathway to the hydroxamic acids **8** and **9** as well as to lactams **10** and **11**. Furthermore, any *N*-nucleophiles like 1,2-phenylenediamine, 2-nitroaniline, acetamidine, semicarbohydrazide or carbohydrazide did not react at all with bromide **3** to form *N*-glycosides or cyclization products. Only the elimination of hydrogen bromide and dark-coloured decomposition products were observed.

The structures of compounds **2**–**17** were assigned by spectroscopic methods. The configurations at tertiary anomeric centres of tetraacetate **2** and lactam **10** were unequivocally elucidated by X-ray analyses [21]. The tetraacetate **2** has the β-D- and the lactam **10** the (2*S*)-configuration. In conclusion, the (2*S*)-configuration of **10** proves also the α-D-configuration of the starting nitrophenyl glycosides **6** and **7** discussed above, because no configurational change is to be expected during their reductive cyclization.

The conformation of the pyranoid ring in compounds **2**–**15** has been studied (Table 1). If a $^{2}C_{5}$ or a $^{5}C_{2}$ conformation is favoured, this results in interactions of the substituents at positions C-3′ and C-4′ of the saccharidic moiety with the nitrophenoxy substituent at C-2′ or the benzoxazinone ring, respectively.

The glycosides **6** and **7** adopt a $^{5}C_{2}$ pyranoid ring geometry indicated by the small H,H coupling constants ($J_{3,4}$ 4.4–4.6, $J_{4,5}$ 3.7–3.8 Hz). According to an empirical increment system for the determination of the optical rotation of pyranoses [22], positive rotation

Table 1
Conformational assignment of the D-*arabino*-hex-2-ulopyranosonates **2**–**15**

Structure	Compound	$[\alpha]_D$ (°)	$J_{3,4}$ (Hz)[a]	$J_{4,5}$ (Hz)[a]	Conformation
	**2**: X = OAc, R = CO_2Me	−132	10.3	3.5	$^2C_5$
	3: X = Br, R = CO_2Me	−80	9.3	3.4	
	4: X = CO_2Me, R = OH	−85	10.1	3.3	
	5: X = OH, R = CO_2Me	−175	10.1	3.2	
	**6**: R = H	+55	4.6	3.8	$^5C_2$
	7: R = OCH_3	+45	4.4	3.7	
	**8**: R = H, R′ = OH	−60	10.6	3.6	$^2C_5$
	9: R = OCH_3, R′ = OH	−66	10.4	3.2	
	10: R = H, R′ = H	−37	10.4	3.6	
	11: R = OCH_3, R′ = H	−44	10.4	3.8	
	**12**: R = H, R′ = OH	−24	9.6	3.7	$^2C_5$
	13: R = OCH_3, R′ = OH	−76	9.5	3.7	
	14: R = H, R′ = H	−16	9.3	3.7	
	15: R = OCH_3, R′ = H	−43	9.1	3.6	

[a] $J_{3',4'}$ and $J_{4',5'}$ for **8**–**15**.

values of **6** and **7** in chloroform are a feature of the $^5C_2$ conformation because of the dominating + synclinal arrangement of the pyranoid substituents. Analogously, the $^2C_5$ conformation of **2**–**5** and **8**–**15** was inferred also from their coupling patterns ($J_{3',4'}$ 9.2–10.4, $J_{4',5'}$ 3.6–3.8 Hz) as well as from their negative values for the optical rotation. A comparison of the $^5C_2$-arranged glycosides **6** and **7** with the cyclization products **8**–**15** shows that the 1,4-benzoxazinone system forces a conformational change back to $^2C_5$ with 3′- and 4′-substituents disposed equatorially as in **2**–**5**.

The glycals **16** and **17** adopt a $^5H_6$ conformation according to their H,H coupling constants. Furthermore, the optical rotation value of glycal **17** is in good agreement with that of 5-di-*O*-acetyl-2,6-anhydro-3-deoxy-D-*erythro*-hex-2-enose, a close analogue with $^5H_6$ conformation [20,23].

3. Experimental

Starting material.—Crystalline methyl β-D-*arabino*-hex-2-ulopyranosonate (**1**) was prepared from a fermentation solution containing D-*arabino*-hex-2-ulopyranosonic acid and sodium D-*arabino*-hex-2-ulopyranosonate [8].

Analytical methods.—Melting points were measured on a Boetius melting point apparatus and are corrected. NMR spectra were recorded with a Varian Gemini 200 (^{1}H, 199.975 MHz; ^{13}C, 50.289 MHz) or Varian Unity 400 (^{1}H, 399.97552 MHz; ^{13}C, 100.577 MHz) using hexamethyldisiloxane as internal reference. Optical rotations were measured with a semiautomatic polarimeter Polartronic-D (Schmidt and Haensch) using the Na–D line. MS measurements were made on a VG 12-250 spectrometer (VG Masslab, Manchester) with 70 eV EI ionization. TLC was performed on precoated Silica Gel 60 F_{254}

aluminium sheets (E. Merck); spots were visualized by gentle heating. Elemental analyses were determined on a Heraeus CHN–O Rapid analyser.

Methyl 2,3,4,5-tetra-O-*acetyl*-β-D-arabino-*hex*-2-*ulopyranosonate* (**2**).—To a stirred suspension of **1** (4.16 g, 20 mmol) in Ac_2O (25 mL) concentrated H_2SO_4 (0.5 mL) was added at 20 °C. The temperature was raised to 60 °C and kept there for 20 min. The solution was cooled and then poured into ice. The precipitate was filtered off, washed with water and recrystallized from MeOH to yield 5.86 g (78%) of **2** as colourless crystals; mp 171 °C, lit 168–169 °C [18]; $[\alpha]_D^{22} - 130°$ (*c* 1.0, $CHCl_3$); R_f 0.43 (1:1 toluene–EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$): δ 5.45 (d, 1 H, $J_{3,4}$ 10.4 Hz, H-3), 5.39 (m, 1 H, H-5), 5.38 (m, 1 H, H-4), 4.02 (d, 1 H, $J_{6a,b}$ 13.4 Hz, H-6b), 3.90 (d, 1 H, $J_{6a,b}$ 13.4 Hz, H-6a), 3.78 (s, 3 H, OCH_3), 2.21 (s, 3 H, OAc), 2.18 (s, 3 H, OAc), 2.04 (s, 3 H, OAc), 2.01 (s, 3 H, OAc); ^{13}C NMR (50 MHz, $CDCl_3$): δ 170.7 (CO), 170.3 (CO), 170.2 (CO), 168.6 (CO), 165.3 (C-1), 96.5 (C-2), 67.9 (C-3), 68.9 (C-4), 67.1 (C-5), 63.9 (C-6), 53.9 (OCH_3), 21.3 (CH_3), 21.2 (CH_3), 21.0 (CH_3), 20.9 (CH_3); EIMS: *m*/*z* (%): 317 (37, $[M]^+$), 275 (11), 257 (5), 233 (7), 216 (10), 197 (16), 170 (40), 155 (19), 128 (40), 115 (18), 43 (100). Anal. Calcd for $C_{15}H_{20}O_{11}$: C, 47.88; H, 5.36. Found: C, 47.80; H, 5.21.

Methyl (3,4,5-tri-O-*acetyl*-β-D-arabino-*hex*-2-*ulopyranosyl)onate bromide* (**3**).—A mixture of powdered **2** (3.76 g, 10 mmol) in a 33% solution of HBr in HOAc (40 mL) was stirred for 2 h at 20 °C. The solution was diluted with ice-cold $CHCl_3$ (60 mL) and poured into ice water (100 mL). The $CHCl_3$ layer was separated and the aq phase extracted again with $CHCl_3$ (15 mL). The $CHCl_3$ extracts were washed successively with ice water (60 mL), twice with a cold solution of $NaHCO_3$ (2%, 60 mL) and again with ice water (60 mL). After drying the colourless solution over $MgSO_4$ the solvent was evaporated to yield 3.89 g (98%) of **3** as colourless powder; mp 78–80 °C; $[\alpha]_D^{22} - 175°$ (*c* 1.0, $CHCl_3$); R_f 0.61 (1:1 toluene–EtOAc); ^{1}H NMR (200 MHz, $CDCl_3$): δ 5.48 (d, 1 H, $J_{3,4}$ 10.0 Hz, 3-H), 5.39 (m, 1 H, H-5), 5.13 (dd, 1 H, $J_{3,4}$ 10.0, $J_{4,5}$ 3.2 Hz, H-4), 4.33 (d, 1 H, $J_{6a,b}$ 13.4 Hz, H-6a), 4.25 (d, 1 H, $J_{6a,b}$ 13.4 Hz, H-6b), 3.85 (s, 3 H, OCH_3), 2.15, (s, 3 H, OAc), 2.10 (s, 3 H, OAc), 2.00 (s, 3 H, OAc); ^{13}C NMR ($CDCl_3$): δ 170.5 (CO), 170.3 (CO), 169.5 (CO), 165.5 (C-1), 95.9 (C-2), 69.9 (C-3), 67.7 (C-4), 67.4 (C-5), 66.9 (C-6), 54.4 (OCH_3), 21.0 (CH_3), 21.3 (CH_3), 21.3 (CH_3); EIMS: *m*/*z* (%) 356 (8, $[M^+ + 2\text{-OAc}]$, 354 (9, $[M^+ - OAc]$, 317 (20, $[M^+ - HBr]$), 259 (12), 197 (17), 173 (23), 155 (39), 128 (37), 43 (100). Anal. Calcd for $C_{13}H_{17}BrO_9$: C, 39.31; H, 4.31. Found: C, 38.66; H, 4.16.

Methyl 2-hydroxy-3,4,5-tri-O-*acetyl*-α-D-arabino-*hex*-2-*ulopyranosonate* (**4**).—To a stirred solution of **3** (1.59 g, 4.0 mmol) in dry acetone (5 mL) water (42 μL, 2.3 mmol) was added at 0 °C with a syringe, and within 10 min Ag_2CO_3 (0.93 g, 3.4 mmol) in portions. After 30 min the mixture was allowed to warm to room temperature (rt) and stirred for an additional 10 min. The resultant silver salts were filtered off, washed with acetone and the filtrate was evaporated. The crude syrup crystallized on treating with diisopropylether (1 mL). Recrystallization from diisopropylether yielded 1.27 g (95%) of **4** as colourless crystals, mp 105–108 °C; $[\alpha]_D^{22} - 85°$ (*c* 1.0, $CHCl_3$); R_f 0.35 (1:1 toluene–EtOAc); ^{1}H NMR (200 MHz, $CDCl_3$): δ 5.58 (dd, 1 H, $J_{3,4}$ 10.1, $J_{4,5}$ 3.2 Hz, H-4), 5.48 (d, 1 H, $J_{3,4}$ 10.1 Hz, H-3), 5.37 (m, 1 H, H-5), 4.59 (s, 1 H, 2-OH), 4.05 (m, 2 H, H-6a, H-6b), 3.95 (s, 3 H, OCH_3), 2.17 (s, 3 H, OAc, 2.05 (s, 3 H, OAc), 2.02 (s, 3 H, OAc); ^{13}C NMR (50 MHz, $CDCl_3$): δ 170.8 (CO), 170.5 (CO), 169.8 (CO), 168.6 (C-1), 96.5 (C-2), 70.2 (C-3), 69.7 (C-4), 68.0 (C-5), 64.8 (C-6), 53.9 (OCH_3), 21.4 ($2 \times CH_3$), 21.1 (CH_3); EIMS: *m*/*z* (%): 334 (7, M^+), 253 (6), 231 (10), 215 (6), 170 (28), 155 (12), 145 (19), 128 (17), 115 (20), 43 (100). Anal. Calcd for $C_{13}H_{18}O_{10}$: C, 46.71; H, 5.43. Found: C, 46.52; H, 5.89.

Methyl 2-hydroxy-3,4,5-tri-O-*acetyl*-β-D-arabino-*hex*-2-*ulopyranosonate* (**5**).—A solution of **4** (67 mg, 0.2 mmol) in $CDCl_3$ (0.8 mL) was kept several days at rt until ^{1}H NMR monitoring showed the reaction to be complete. The solvent was evaporated to yield 67 mg (100%) of **5** as colourless syrup; $[\alpha]_D^{22} - 80°$

(c 1.0, $CHCl_3$); R_f 0.35 (1:1 toluene–EtOAc); ^1H NMR (200 MHz, $CDCl_3$): δ 5.60 (d, 1 H, $J_{3,4}$ 9.3 Hz, H-3), 5.38 (m, 1 H, H-5), 5.35 (dd, 1 H, $J_{3,4}$ 9.3, $J_{4,5}$ 3.2 Hz, 4-H), 4.39 (d, 1 H, $J_{3,2\text{-OH}}$ 1.0 Hz, 2-OH), 4.23 (d, 1 H, $J_{6a,b}$ 13.1 Hz, H-6b), 3.85 (s, 3 H, OCH_3), 3.81 (m, 1 H, H-6a), 2.18 (s, 3 H, OAc), 2.02 (s, 3 H, OAc), 1.98 (s, 3 H, OAc); ^{13}C NMR (50 MHz, $CDCl_3$): δ 170.9 (CO), 170.4 (CO), 170.1 (CO), 169.2 (C-1), 95.3 (C-2), 69.3 (C-4), 68.7 (C-5), 68.5 (C-3), 63.1 (C-6), 54.4 (OCH_3), 21.5 (CH_3), 21.1 ($2 \times CH_3$); EIMS: m/z (%): 318 (14), 276 (32, $[M^+ - COOCH_3]$), 234 (22), 215 (20), 187 (8), 170 (10), 128 (17), 115 (9), 44 (100). Anal. Calcd for $C_{13}H_{18}O_{10}$: C, 46.71; H, 5.43. Found: C, 46.63; H, 5.78.

General procedure for the glycosidation to form the phenyl glycosides **6** *and* **7**.—To a stirred solution of **3** (1.98 g, 5.0 mmol) in dry acetone (50 mL) were added the corresponding pure phenol (0.77 g, 5.5 mmol of 2-nitrophenol for **6**; 1.14 g, 5.5 mmol of 5-methoxy-2-nitrophenol for **7**) and K_2CO_3 (1.38 g, 5.0 mmol). After refluxing (3 h for **6**; 8 h for **7**) $CHCl_3$ (30 mL) was added and the mixture was cooled to 0 °C. The solid was filtered off and washed with $CHCl_3$. The filtrate was evaporated and the resulting syrup was purified by column chromatography with 3:1 toluene–EtOAc.

Methyl (2-nitrophenyl 3,4,5-tri-O-*acetyl*-α-D-arabino-*hex*-2-*ulopyranosid)onate* (**6**).—Crystallization of the syrupy product fraction from MeOH gave 2.18 g (96%) of **6** as pale yellow crystals; mp 46–47 °C; $[\alpha]_D^{22} + 55°$ (c 1.0, $CHCl_3$,); CD $\Delta\varepsilon_{235} - 17.2$, $\Delta\varepsilon_{280} + 4.0$, $\Delta\varepsilon_{343} + 3.1$ (c 0.54, $CHCl_3$); R_f 0.64 (toluene–EtOAc, 1:1 v/v); ^1H NMR (400 MHz, $CDCl_3$): δ 7.70 (dd, 1 H, $J_{3,4}$ 8.0, $J_{3,5}$ 1.5 Hz, H-3^{Ar}), 7.43 (m, 2 H, 4-, H-6^{Ar}), 7.16 (m, 1 H, H-5^{Ar}), 5.49 (d, 1 H, $J_{3,4}$ 4.6 Hz, 3-H), 5.37 (dd, 1 H, $J_{3,4}$ 4.6, $J_{4,5}$ 3.2 Hz, H-4), 5.34 (m, 1 H, H-5), 4.07 (m, 2 H, H-6a, H6-b), 3.62 (s, 3 H, OCH_3), 2.12 (s, 3 H, OAc), 2.04 (s, 3 H, OAc), 1.97 (s, 3 H, OAc); ^{13}C NMR (50 MHz, $CDCl_3$): δ 170.5 (CO), 170.2 (CO), 168.6 (CO), 165.9 (C-1), 147.2 (C-1Ar), 142.1 (C-2Ar), 133.9 (C-5Ar), 125.7 (C-3Ar), 123.6 (C-4Ar), 119.1 (C-6Ar), 100.3 (C-2), 70.1 (C-3), 67.1 (C-4), 64.6 (C-5), 60.5 (C-6), 53.8 (OCH_3), 21.9 (CH_3), 21.1 (CH_3), 21.0 (CH_3); EIMS: m/z (%): 455 (1, $[M^+]$), 396 (5, $[M^+ - COOCH_3]$), 317 (30), 257 (3), 215 (8), 197 (30), 155 (52), 42 (100). Anal. Calcd for $C_{19}H_{21}NO_{12}$: C, 50.11; H, 4.65; N, 3.07. Found: C, 50.09; H, 4.69; N, 2.75.

Methyl (5-methoxy-2-nitrophenyl 3,4,5-tri-O-*acetyl*-α-D-arabino-*hex*-2-*ulopyranosid)onate* (**7**).—Column chromatography gave successively 0.65 g (33%) of recovered **3** and a product fraction which was crystallized from MeOH to give 1.14 g (47%) of **7** as pale yellow crystals; mp 54–57 °C; $[\alpha]_D^{22} + 45°$ (c 1.0, $CHCl_3$); R_f 0.36 (2:1 toluene–EtOAc); ^1H NMR (400 MHz, $CDCl_3$): δ 7.89 (d, 1 H, $J_{3,4}$ 9.2 Hz, H-3Ar), 6.96 (d, 1 H, $J_{4,6}$ 2.4 Hz, H-6Ar), 6.59 (dd, 1 H, $J_{3,4}$ 9.2, $J_{4,6}$ 2.4 Hz, H-4Ar), 5.53 (d, 1 H, $J_{3,4}$ 4.4 Hz, H-3), 5.40 (m, 1 H, H-4), 5.37 (m, 1 H, H-5), 4.12 (m, 2 H, H-6a, H-6b), 3.80 (s, 3 H, OCH_3), 3.63 (s, 3 H, $COOCH_3$), 2.15 (s, 3 H, OAc), 2.08 (s, 3 H, OAc), 2.02 (s, 3 H, OAc); ^{13}C NMR (50 MHz, $CDCl_3$): δ 170.6 (CO), 170.2 (CO), 168.6 (CO), 166.0 (C-5Ar), 164.3 (C-1), 149.9 (C-1Ar), 135.0 (C-2Ar), 128.2 (C-3Ar), 108.5 (C-4Ar), 104.7 (C-6Ar), 100.4 (C-2), 69.9 (C-3), 67.1 (C-4), 64.6 (C-5), 60.5 (C-6), 56.4 (OCH_3), 53.7 (CO_2CH_3), 21.0 (CH_3), 20.9 ($2 \times CH_3$), EIMS: m/z (%): 485 (7, $[M^+]$), 426 (21), 317 (100), 257 (11), 215 (16), 197 (53), 156 (46). Anal. Calcd for $C_{20}H_{23}NO_{13}$: C, 49.49; H, 4.77; N, 2.88. Found: C, 49.36; H, 4.83; N, 2.53.

General procedure for the reduction of the glycosides **6** *and* **7** *with Zn and* NH_4Cl.—To a solution of 2.0 mmol of the corresponding glycoside (0.91 g of **6**; 0.97 g of **7**) in MeOH (25 mL) were added NH_4Cl (0.53 g, 10 mmol) and zinc dust (0.65 g, 10 mmol). After the mixture was stirred for 2 h at rt the solids were filtered off and washed carefully with 7:3 $CHCl_3$–MeOH. The filtrate was evaporated and the resulting products were purified by column chromatography. First, the glycal and the lactam fraction were eluted with 1:1 toluene–EtOAc. Then, the hydroxamic acid fraction was eluted with $CHCl_3$–MeOH (12:1 for **8**, 7:3 for **9**). The violet hydroxamic acid fraction was treated with an ion-exchange resin (Amberlite IR 120 (H^+)) to remove any metal ions. The fractions were evaporated to dryness and crystallized as described.

Reduction of **6** gave successively:

Methyl 3,4,5-tri-O-*acetyl*-D-erythro-*hex*-2-*enopyranosonate* (**16**).—A total of 12 mg (2%) of **16** were obtained as colourless syrup; R_f 0.35 (3:1 toluene–EtOAc); ^{1}H NMR (200 MHz, $CDCl_3$): δ 5.77 (dd, 1 H, $J_{4,5}$ 4.4, $J_{4,6b}$ 1.3 Hz, H-4), 5.29 (ddd, 1 H, $J_{5,6a}$ 9.3, $J_{4,5}$ 4.4, $J_{5,6b}$ 3.6 Hz, H-5), 4.21 (ddd, 1 H, $J_{6a,b}$ 11.0, $J_{5,6b}$ 3.6, $J_{4,6b}$ 1.3 Hz, H-6b), 4.07 (dd, 1 H, $J_{6a,b}$ 11.0, $J_{5,6a}$ 9.3 Hz, H-6a), 3.80 (s, 3 H, OCH_3), 2.18 (s, 3 H, OAc), 2.10 (s, 3 H, OAc), 2.00 (s, 3 H, OAc); ^{13}C NMR (50 MHz, $CDCl_3$): δ 170.6 (CO), 170.0 (2 × CO), 161.1 (C-1), 139.6 (C-2), 133.0 (C-3), 65.1 (C-4, and C-5), 64.3 (C-6), 53.1 (OCH_3), 21.0 (2 × CH_3), 20.9 (CH_3); EIMS: *m*/*z* (%): 274 (17, [$M^+ - CH_3OH$]), 257 (42, [$M^+ - COOCH_3$]), 215 (40), 197 (66), 172 (42), 155 (100).

*(2*S*)-3′,4′,5′-Tri*-O-*acetyl*-D-arabino-*2*H-*1,4-benzoxazin-2-spiro-2′-pyran-3(4*H*)-one* (**10**).—A total of 63 mg (8%) of **10** crystallized from MeOH as colourless prisms; mp 207–208 °C; $[\alpha]_D^{22}$ − 37° (*c* 1.0, $CHCl_3$,); CD $\Delta\varepsilon_{236}$ + 43.9, $\Delta\varepsilon_{259}$ −7.6 (*c* 0.49, $CHCl_3$,); R_f 0.54 (1:1 toluene–EtOAc); ^{1}H NMR (200 MHz, $CDCl_3$): δ 9.60 (s, 1 H, NH), 6.92–7.20 (m, 4H_{arom}), 6.12 (dd, 1 H, $J_{3',4'}$ 10.4, $J_{4',5'}$ 3.6 Hz, H-4′), 5.72 (d, 1 H, $J_{3',4'}$ 10.4 Hz, H-3′), 5.43 (m, 1 H, H-5′), 4.03 (m, 2 H, H-6′a, H-6′b), 2.19 (s, 3 H, OAc), 2.01 (s, 6 H, 2 OAc); ^{13}C NMR (50 MHz, $CDCl_3$): δ 21.1 (CH_3), 21.2 (CH_3), 21.4 (CH_3), 65.9 (C-6′), 68.4 (C-5′), 70.0 (C-4′), 70.1 (C-3′), 98.1 (C-2), 116.0 (C-8), 118.3 (C-6), 124.2 (C-5), 124.9 (C-7), 125.0 (C-4a), 140.8 (C-8a), 161.4 (C-3), 170.2 (CO), 170.6 (CO), 171.1 (CO); EIMS: *m*/*z* (%): 393 (40, [M^+]), 351 (5), 249 (4), 164 (37), 136 (40), 42 (100). Anal. Calcd for $C_{18}H_{19}NO_9$: C, 54.96; H, 4.87; N, 3.56. Found: C, 54.60; H, 4.85; N, 3.47.

*(2*S*)-3′,4′,5′-Tri*-O-*acetyl*-D-arabino-*4-hydroxy-2*H-*1,4-benzoxazin-2-spiro-2′-pyran-3(4*H*)-one* (**8**).—A total of 690 mg (85%) of **8** crystallized from MeOH as colourless needles; mp 100–101 °C; $[\alpha]_D^{22}$ − 60° (*c* 1.00, $CHCl_3$); CD $\Delta\varepsilon_{235}$ + 16.7, $\Delta\varepsilon_{258}$ −5.7 (*c* 0.41, $CHCl_3$); R_f 0.56 ($CHCl_3$–MeOH, 12:1 v/v); ^{1}H NMR (200 MHz, $CDCl_3$): δ 9.45 (s, 1 H, OH), 7.40 (d, 1 H, $J_{5,6}$ 8.0 Hz, H-5), 7.10 (m, 3 H, H-6, H-7, H-8), 6.00 (dd, 1 H, $J_{3',4'}$ 10.4, $J_{4',5'}$ 3.6 Hz, H-4′), 5.68 (d, 1 H, $J_{3',4'}$ 10.6 Hz, H-3′), 5.32 (m, 1 H, H-5′), 3.91 (m, 2 H, H-6′a, H-6′b), 2.16 (s, 3 H, OAc), 2.00 (s, 6 H, 2 OAc); ^{13}C NMR (50 MHz, $CDCl_3$): δ 171.0 (CO), 170.6 (CO), 170.1 (CO), 156.1 (C-3), 140.2 (C-8a), 125.9 (C-4a), 125.8 (C-6), 124.3 (C-7), 117.9 (C-8), 113.8 (C-5), 99.7 (C-2), 70.1 (C-3′), 69.9 (C-4′), 68.2 (C-5′), 66.1 (C-6′), 21.3 (CH_3), 21.1 (CH_3), 20.0 (CH_3); EIMS: *m*/*z* (%): 409 (28, [M^+]), 393 (12), 381 (3), 367 (22), 349 (10), 233 (31), 215 (20), 202 (11), 44 (100), 275 (47). Anal. Calcd for $C_{18}H_{19}NO_{10}$: C, 52.82; H, 4.68; N, 3.42. Found: C, 52.29; H, 5.28; N, 3.40.

Reaction of **7** gave successively:

Methyl 4,5-di-O-*acetyl-2,6-anhydro-3-deoxy*-D-erythro-*hex*-2-*enosonate* (**17**).—A total of 46 mg (9%) of **17** was obtained as colourless syrup; $[\alpha]_D^{22}$ + 178° (*c* 1.0, $CHCl_3$); R_f 0.55 (1:1 toluene–EtOAc); ^{1}H NMR (200 MHz, $CDCl_3$): δ 5.97 (d, 1 H, $J_{3,4}$ 4.4 Hz, H-3), 5.59 (dd, 1 H, $J_{3,4}$ 4.4, $J_{4,5}$ 3.8 Hz, H-4), 5.24 (m, 1 H, H-5), 4.20 (m, 2 H, H-6′a, H-6′b), 3.66 (s, 3 H, OCH_3), 2.07 (s, 6 H, 2 OAc); ^{13}C NMR (50 MHz, $CDCl_3$): δ 170.5 (CO), 170.3 (CO), 162.5 (C-1), 146.6 (C-2), 106.5 (C-3), 65.3 (C-6), 64.8 (C-4), 63.4 (C-5), 53.1 (OCH_3), 21.2 (2 × CH_3); EIMS: *m*/*z* (%): 199 (23, [$M^+ - COOCH_3$]), 156 (17), 139 (100). Anal. Calcd for $C_{11}H_{14}O_7$: C, 55.82; H, 5.46. Found: C, 55.62; H, 5.21.

*(2*S*)-3′,4′,5′-Tri*-O-*acetyl-7-methoxy*-D-arabino-*2*H-*1,4-benzoxazin-2-spiro-2′-pyran-3(4*H*)-one* (**11**).—A total of 118 mg (14%) of **11** crystallized from MeOH as colourless needles; mp 235–236 °C; $[\alpha]_D^{22}$ − 44° (*c* 1.0, $CHCl_3$); R_f 0.48 (toluene–EtOAc, 1:1 v/v); ^{1}H NMR (200 MHz, $CDCl_3$): δ 11.13 (s, 1 H, NH), 6.81 (d, 1 H, $J_{5,6}$ 8.8 Hz, H-5), 6.70 (d, 1 H, $J_{6,8}$ 2.6 Hz, H-8), 6.59 (dd, 1 H, $J_{5,6}$ 8.8, $J_{6,8}$ 2.6 Hz, H-6), 6.13 (dd, 1 H, $J_{3',4'}$ 10.4, $J_{4',5'}$ 3.8 Hz, H-4′), 5.70 (d, 1 H, $J_{3',4'}$ 10.4 Hz, H-3′), 5.43 (m, 1 H, H-5′), 4.05 (m, 2 H, H-6′a, H-6′b), 3.74 (s, 3 H, OCH_3), 2.11 (s, 3 H, OAc), 1.99 (s, 3 H, OAc), 1.92 (s, 3 H, OAc); ^{13}C NMR (50 MHz, $CDCl_3$): δ 171.0 (CO), 170.5 (CO), 170.3 (CO), 159.7 (C-7), 156.8 (C-3), 141.5 (C-8a), 119.5 (C-4a), 116.9 (C-5), 110.6 (C-6), 103.7 (C-8), 98.0 (C-2), 70.0 (C-4′), 69.9 (C-3′), 68.4 (C-5′), 65.9 (C-6′), 56.1 (OCH_3), 21.4 (CH_3), 21.2 (CH_3), 21.1 (CH_3); EIMS: *m*/*z* (%): 423 (23, [M^+]), 381

(5), 364 (4), 261 (7), 194 (13), 165 (42), 42 (100). Anal. Calcd for $C_{19}H_{21}NO_{10}$: C, 53.90; H, 5.00; N, 3.31. Found: C, 53.59; H, 4.81; N, 3.11.

(2S)-3′,4′,5′-Tri-O-acetyl-D-arabino-4-hydroxy-7-methoxy-2H-1,4-benzoxazin-2-spiro-2′-pyran-3(4H)-one (**9**).—A total of 470 mg (54%) of **9** crystallized from $CHCl_3$–MeOH as colourless crystals; mp 105–107 °C; $[\alpha]_D^{22} - 66°$ (*c* 1.0, $CHCl_3$); R_f 0.32 ($CHCl_3$–MeOH, 7:3 v/v); ^{1}H NMR (200 MHz, $CDCl_3$): δ 11.27 (s, 1 H, OH), 7.23 (d, 1 H, $J_{5,6}$ 8.8 Hz, H-5), 6.77 (d, 1 H, $J_{6,8}$ 2.0 Hz, H-8), 6.67 (dd, 1 H, $J_{5,6}$ 8.8, $J_{6,8}$ 2.0 Hz, H-6), 6.04 (dd, 1 H, $J_{3,4}$ 10.2, $J_{4,5}$ 3.2 Hz, H-4′), 5.45 (d, 1 H, $J_{3',4'}$ 10.4 Hz, H-3′), 5.32 (m, 1 H, H-5′), 3.94 (m, 2H, H-6′a, H-6′b), 3.70 (s, 3 H, OCH_3), 2.12 (s, 3 H, OAc), 1.98 (s, 3 H, OAc), 1.92 (s, 3 H, OAc); ^{13}C NMR (50 MHz, $CDCl_3$): (170.8 (CO), 170.6 (CO), 170.3 (CO), 157.3 (C-7), 154.8 (C-3), 141.5 (C-8a), 122.3 (C-4a), 115.0 (C-5), 110.1 (C-6), 103.5 (C-8), 100.1 (C-2), 70.0 (C-4′), 70.2 (C-3′), 68.4 (C-5′), 66.1 (C-6′), 56.5 (OCH_3), 21.5 (CH_3), 21.3 ($2 \times CH_3$); EIMS: *m/z* (%): 439 (34, $[M^+]$), 422 (61), 395 (3), 380 (14), 233 (22), 215 (59), 206 (38), 43 (100). Anal. Calcd for $C_{19}H_{21}NO_{11}$: C, 51.94; H, 4.82; N, 3.91. Found: C, 51.78; H, 4.50; N, 3.42.

General procedure for the catalytic hydrogenation of the glycosides **6** *and* **7**.—A solution of the corresponding glycoside (0.91 g, 2 mmol of **6**; 0.97 g, 2 mmol of **7**) in MeOH (20 mL) was hydrogenated over 5% Pt–C (0.11 g) at normal pressure and rt until the consumption of hydrogen was complete. The catalyst was filtered off and the filtrate evaporated.

The products resulting from **6** were purified as described above to give 190 mg (23%) of **8** and 570 mg (72%) of **10**.

The product resulting from **7** was recrystallized (MeOH) to give 800 mg (95%) of **11**.

Alternative synthesis of **10** *by cyclization of* **3** *with 2-aminophenol*.—To a stirred solution of **3** (2.38 g, 6.0 mmol) and 2-aminophenol (0.71 g, 6.5 mmol) in dry acetone (850 mL) was added powdered K_2CO_3. The suspension was refluxed for 6 h, then cooled to 0 °C, filtered and the solid remaining washed with acetone (10 mL). The filtrate was evaporated to dryness in vacuo. The brown syrup obtained was subjected to column chromatography (3:1 toluene–EtOAc) to give by crystallization from MeOH 490 mg (21%) of **10** as colourless crystals.

General procedure for the deacetylation to form **12**, **13**, **14** *and* **15**.—A solution of 0.5 mmol of the corresponding acetate (204 mg **8** for **12**; 218 mg **9** for **13**; 196 mg **10** for **14**; 211 mg **11** for **15**) was stirred in a solution of NaOMe in MeOH (8 mL, 0.1 M) for 15 min. The solution was neutralized by addition of an ion-exchange resin (Amberlite IR 120 (H^+)). The resin was filtered off and the filtrate evaporated. The residue was recrystallized from 7:3 $CHCl_3$–MeOH.

(2S)-3′,4,4′,5′-Tetrahydroxy-D-arabino-2H-1,4-benzoxazin-2-spiro-2′-pyran-3(4H)-one (**12**).—A total of 134 mg (95%) of **12** was obtained as colourless crystals; mp 211–212 °C; $[\alpha]_D^{22} - 24°$ (*c* 1.0, MeOH–WATER 1:1, v/v,); CD $\Delta\varepsilon_{234} + 25.3$, $\Delta\varepsilon_{258} - 10.8$ (*c* 0.41, MeOH,); ^{1}H NMR (200 MHz, CD_3OD): δ 7.08–7.40 (m, $4H_{arom}$), 4.65 (dd, 1 H, $J_{3',4'}$ 9.5, $J_{4',5'}$ 3.7 Hz, H-4′), 4.07 (d, 1 H, $J_{3',4'}$ 9.6 Hz, H-3′), 3.96 (m, 1 H, H-5′), 3.63 (m, 2H, H-6′a, H-6′b); ^{13}C NMR (50 MHz, CD_3OD): δ 158.9 (C-3), 142.7 (C-8a), 129.3 (C-4a), 125.7 (C-6), 124.3 (C-7), 118.1 (C-8), 114.6 (C-5), 102.3 (C-2), 74.6 (C-3′), 72.4 (C-4′), 69.9 (C-5′), 68.7 (C-6′); EIMS: *m/z* (%): 283 (37, $[M^+]$), 266 (6), 255 (22), 164 (100), 136 (100). Anal. Calcd for $C_{12}H_{13}NO_7$: C, 50.89; H, 4.62; N, 4.94. Found: C, 50.88; H, 4.97; N, 4.84.

(2S)-3′,4,4′,5′-Tetrahydroxy-D-arabino-7-methoxy-2H-1,4-benzoxazin-2-spiro-2′-pyran-3(4H)-one (**13**).—A total of 152 mg (97%) of **13** was obtained as colourless needles; mp 205–207 °C; $[\alpha]_D^{22} - 76°$ (*c* 1.0, MeOH); ^{1}H NMR (200 MHz, CD_3OD): δ 7.89 (s, 1 H, OH), 7.23 (d, 1 H, $J_{5,6}$ 9.5 Hz, 5-H), 6.68 (m, 2H, 6-, 8-H), 4.56 (dd, 1 H, $J_{3',4'}$ 9.5, $J_{4',5'}$ 3.7 Hz, H-4′), 4.02 (d, 1 H, $J_{3',4'}$ 9.5 Hz, H-3′), 3.93 (m, 1 H, H-5′), 3.86 (m, 2H, H-6′a, H-6′b), 3.77 (s, 3 H, OCH_3); ^{13}C NMR (50 MHz, CD_3OD): δ 158.7 (C-7), 158.4 (C-3), 143.3 (C-8a), 123.0 (C-4a), 114.7 (C-5), 109.4 (C-6), 104.7 (C-8), 102.5 (C-2), 74.5 (C-3′), 72.3 (C-4′), 69.8 (C-5′), 68.6 (C-6′), 56.4 (OCH_3); EIMS: *m/z* (%): 313 (3, $[M^+]$), 296 (5), 215 (38), 200 (19), 165 (7), 45 (100). Anal.

Calcd for $C_{13}H_{15}NO_8$: C, 49.84; H, 4.83; N, 4.47. Found: C, 49.80; H, 4.54; N, 4.83.

(2S)-3′,4′,5′-Trihydroxy-D-arabino-*2H-1,4-benzoxazin-2-spiro-2′-pyran-3(4H)-one* (**14**). —A total of 155 mg (94%) of **14** was obtained as colourless crystals; mp 126–127 °C; $[\alpha]_D^{22}$ −16° (*c* 1.0, MeOH); CD $\Delta\varepsilon_{236}$ + 48.2, $\Delta\varepsilon_{261}$ − 10.0 (*c* 0.40, MeOH); ^{1}H NMR (200 MHz, CD_3OD): δ 9.45 (s, 1 H, NH), 7.04–6.91 (m, $4H_{arom}$), 4.53 (dd, 1 H, $J_{3',4'}$ 9.3, $J_{4',5'}$ 3.7 Hz, 4′-H), 4.03 (d, 1 H, $J_{3',4'}$ 9.3 Hz, H-3′), 3.92 (m, 1 H, H-5′), 3.84 (m, 2H, H-6′a, H-6′b); ^{13}C NMR (50 MHz, CD_3OD): δ 163.5 (C-3), 142.7 (C-8a), 127.3 (C-4a), 125.7 (C-7), 124.3 (C-5), 118.1 (C-6), 114.6 (C-8), 99.0 (C-2), 72.9 (C-3′), 71.1 (C-4′), 68.5 (C-5′), 67.0 (C-6′); EIMS: *m/z* (%): 267 (52, [M$^+$]), 249 (3), 223 (4), 164 (100), 136 (30). Anal. Calcd for $C_{12}H_{13}NO_6 \cdot H_2O$: C, 50.53; H, 5.30; N, 4.91. Found: C, 50.94; H, 5.43; N, 4.95.

(2S)-3′,4′,5′-Trihydroxy-7-methoxy-D-arabino-*2H-1,4-benzoxazin-2-spiro-2′-pyran-3(4H)-one* (**15**).—A total of 146 mg (98%) of **15** was obtained as colourless crystals; mp 251–252 °C; $[\alpha]_D^{22}$ −43° (*c* 0.859, MeOH–WATER, 6:1 v/v); ^{1}H NMR (400 MHz, CD_3OD): δ 6.81 (d, 1 H, $J_{5,6}$ 8.7 Hz, H-5), 6.67 (d, 1 H, $J_{6,8}$ 1.1 Hz, H-8), 6.57 (dd, 1 H, $J_{5,6}$ 8.7, $J_{6,8}$ 1.1 Hz, H-6), 4.50 (dd, 1 H, $J_{3',4'}$ 9.1, $J_{4',5'}$ 3.6 Hz, H-4′), 4.00 (d, 1 H, $J_{3',4'}$ 9.2 Hz, H-3′), 3.91 (m, 1 H, H-5′), 3.87 (d, 1 H, $J_{6a,6b}$ 12.3 Hz, H-6′b), 3.81 (d, 1 H, $J_{6'a,6'b}$ 12.3 Hz, H-6′a), 3.74 (s, 3 H, OCH_3); ^{13}C NMR (100 MHz, CD_3OD): δ 162.8 (C-7), 157.9 (C-3), 143.3 (C-8a), 120.6 (C-4a), 116.6 (C-5), 109.4 (C-6), 104.5 (C-8), 99.9 (C-2), 73.9 (C-3′), 72.1 (C-4′), 69.3 (C-5′), 67.8 (C-6′), 56.1 (OCH_3); EIMS: *m/z* (%): 297 (7, [M$^+$]), 221 (2), 209 (4), 196 (100), 167 (25), 151 (11). Anal. Calcd for $C_{13}H_{15}NO_7$: C, 52.53; H, 5.09; N, 4.71. Found: C, 52.22; H, 5.47; N, 4.58.

Alternative synthesis of methyl 4,5-di-O-acetyl-2,6-anhydro-3-deoxy-D-erythro-*hex-2-enosonate* (**17**).—To a stirred solution of **3** (397 mg, 1.0 mmol) in dry toluene (12 mL) was added dry pyridine (97 μL, 1.2 mmol) and zinc dust (0.33 g, 5.0 mmol). The mixture was heated at 80–90 °C for 2 h and than refluxed for another 15 min. The zinc residue was filtered off, washed with toluene and the filtrate was evaporated. The resulting residue was immediately purified by column chromatography with toluene–EtOAc (1:1, v/v) to give 237 mg (92%) of **17** as colourless syrup.

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References

[1] F.W. Lichtenthaler, *Carbohydrates as Organic Raw Materials*, VCH, Weinheim, 1990.
[2] M. Bols, *Carbohydrate Building Blocks*, Wiley, New York, 1996.
[3] P. Fahrni, T. Siegfried, Eur. Patent EP 133 493 (1985); *Chem. Abstr.*, 103 (1985), 178578c.
[4] (a) W.N. Haworth, E.L. Hirst, *J. Chem. Soc.*, (1926) 1858–1868. (b) W.N. Haworth, E.L. Hirst, A. Learner, *J. Chem. Soc.*, (1927) 1040–1049. (c) C.G. Anderson, W. Charlton, W.N. Haworth, V.S. Nicholson, *J. Chem. Soc.*, (1929) 1337–1346. (d) M.L. Wolfrom, W.W. Binkley, W.L. Shilling, H.W. Hilton, *J. Am. Chem. Soc.*, 73 (1951) 3553–3557.
[5] (a) M. Bobek, J. Farkas, F. Sorm, *Collect. Czech. Chem. Commun.*, 32 (1967) 3572–3580. (b) H. Ohle, *Ber. Dtsch. Chem. Ges.*, 67 (1934) 155–162.
[6] J. Geigert, S.L. Neidleman, D.S. Hirano, B. Wolf, B.M. Panschar, *Carbohydr. Res.*, 113 (1983) 163–165.
[7] O.M.M. Bouvet, P. Lenormand, P.A.D. Grimont, *Int. J. Syst. Bacteriol.*, 39 (1989) 61–67.
[8] S. Kirrbach, R.-R. Schnelle, S. Hauptmann, G. Mann, H. Wilde, D. Sicker, U. Stottmeister, *J. Prakt. Chem.*, 334 (1992) 537–539.
[9] T.C. Crawford, G.C. Andrews, H. Faubl, G.N. Chmurny, *J. Am. Chem. Soc.*, 102 (1980) 2220–2225.
[10] D. Sicker, H. Hartenstein, M. Kluge, Natural benzoxazinoids—Synthesis of acetal glucosides, aglucones, analogues, in S.G. Pandalai (Ed.), *Recent Research Developments in Phytochemistry*, Vol. 1, Research Signpost, Trivandrum, India, 1997, pp. 203–223.
[11] M. Kluge, H.J. Grambow, D. Sicker, *Phytochemistry*, 44 (1997) 639–641.
[12] R.B. Wolf, G.F. Spencer, R.D. Plattner, *J. Nat. Prod.*, 48 (1985) 59–63.
[13] S. Özden, T. Özden, J. Attila, M. Kücükislamoglu, A. Okatan, *J. Chromatogr.*, 609 (1992) 402–406.
[14] K. Pratt, P. Kumar, W.S. Chilton, *Biochem. Syst. Ecol.*, 23 (1995) 781–785.
[15] M. Kluge, D. Sicker, *Tetrahedron*, 52 (1996) 10389–10398.

[16] M. Kluge, B. Schneider, D. Sicker, *Carbohydr. Res.*, 298 (1997) 147–152.
[17] H. Ohle, R. Wolter, *Ber. Dtsch. Chem. Ges.*, 63 (1930) 843–852.
[18] M. Major, W.J. Cook, *J. Am. Chem. Soc.*, 58 (1936) 2477–2478.
[19] H. Hartenstein, D. Sicker, *J. Prakt. Chem.*, 335 (1993) 359–362.
[20] L. Somsák, I. Bajaza, L. Kossuth, *Liebigs Ann. Chem.*, (1990) 1265–1268.
[21] J. Andersch, PhD thesis, Fakultät für Chemie und Mineralogie der Universität Leipzig, 1998.
[22] J. Lehmann, *Kohlenhydrate*, Georg Thieme Verlag, Stuttgart, 1996, pp. 49–54.
[23] P. Köll, E. Steinweg, J. Metzger, B. Meyer, *Liebigs Ann. Chem.* (1982) 1052–1062.