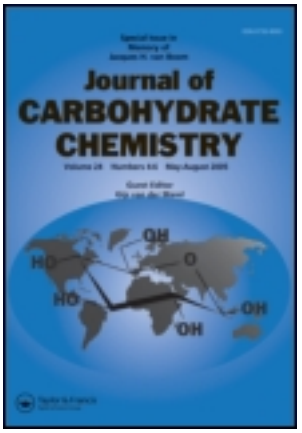

Journal of Carbohydrate Chemistry
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/lcar20

A Simple Synthesis of D-Galactono-1,4-Lactone and Key Building Blocks for the Preparation of Galactofuranosides

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Published online: 14 Dec 2011.

To cite this article: Vincent Lemau de Talancé , Emilie Thiery , Guillaume Eppe , Sandy El Bkassiny , Jérémie Mortier & Stéphane P. Vincent (2011): A Simple Synthesis of D-Galactono-1,4-Lactone and Key Building Blocks for the Preparation of Galactofuranosides, Journal of Carbohydrate Chemistry, 30:7-9, 605-617

To link to this article: http://dx.doi.org/10.1080/07328303.2011.616273

Journal of Carbohydrate Chemistry, 30:605–617, 2011

ISSN: 0732-8303 print / 1532-2327 online
DOI: 10.1080/07328303.2011.616273

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The oxidation of D-galactose by Br_2 to yield D-galactono-1,4-lactone was developed and applied to the preparation of key building blocks for the synthesis of galactofuranosides. Three D-galactono-1,4-lactone derivatives protected as acetates, TBDMS ether, or acetonide were directly obtained in two steps on multigram scale with only one purification step. A mild deacetylation methodology afforded pure D-galactono-1,4-lactone and a new reduction of the lactone functionality using K-selectride was also optimized.

Keywords Lactone; Galactofuranose; Arabinogalactan; Anomeric oxidation

INTRODUCTION

D-Galactofuranose (Gal*f*), the thermodynamic less stable form of D-galactose, is a major component of bacterial glycoconjugates, including severe pathogens such as *Mycobacterium tuberculosis* and *Klebsiella pneumoniae*.[1] Galactofuranosides have also been found in parasites and eukaryotes but never in mammals.[2] Therefore, the enzymes responsible for the biosynthesis of galactofuranosides have become major targets for developing novel antibacterial agents.[3,4] Thus, the efficient and selective access to galactofuranosides from the corresponding pyranose is highly desirable to allow the preparation

Received June 6, 2011; accepted August 17, 2011.
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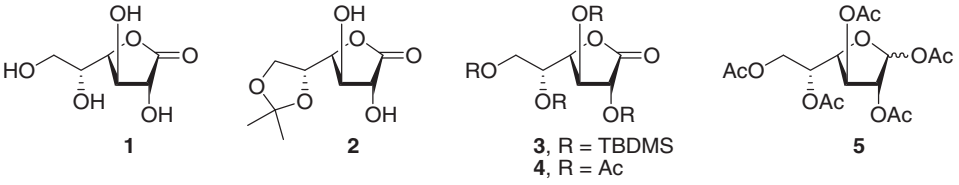


Figure 1: D-Galactono-1,4-lactone and derivatives.

of, for instance, bacterial cell wall fragments,[5] UDP-Gal*f*,[6–8] the biosynthetic precursor of natural galactofuranosides, or glycomimetics based on the Gal*f* scaffold.[9]

Under specific conditions, galactofuranosides can be obtained in good yields directly from D-galactose, either through benzoylation[10,11] or under Fischer glycosylation conditions.[8,12,13] Additionally, galactofuranosides have been obtained from glycosyl acyclic dithioacetal[5,14] and by direct allylation of D-galactose in DMPU.[15] On the other hand, D-galactono-1,4-lactone (or γ-galactonolactone) **1** (Fig. 1) has been widely used as starting material for many applications.[10,16–18] In our laboratory, lactone **1** was exploited as starting material for the construction of inactivators and conformational probes of UDP-galactopyranose mutase (UGM), a key enzyme involved in the mycobacterial cell wall biosynthesis.[19,20]

A new robust and cheap synthesis that can provide multigram quantities of D-galactono-1,4-lactone **1** is therefore highly desired. Here we report a novel simple synthesis of lactone **1** from D-galactose and its transformation to key building blocks **2**–**5** (Fig. 1), ready for further derivatization into galactofuranosides.

RESULTS AND DISCUSSION

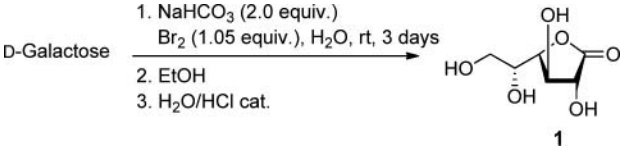
The first synthesis of **1** was based on the reduction of galacturonic salt by sodium borohydride followed by lactonization.[21] In 1974, Kurz et al. described an elegant preparation of **1** based on enzymatic reactions.[22] Later, Vekemans et al. described the direct oxidation of D-galactose under a controlled pressure of oxygen in aqueous sodium hydroxide solution in the presence of palladium on charcoal.[23] The technical difficulty of this synthesis is to maintain a constant pH and a constant oxygen pressure.[24] The gamma–D–galactonolactone **1** was also prepared by hydrolysis of D-galactose *N*,*N*′-diphenylformazan that requires a preliminary multistep synthesis.[25] Another strategy consists of the methanolysis of 2,3,4,6-tetra-*O*-acetyl-1-bromo-β-D-galactopyranosyl chloride, to give quantitatively galactonolactone **1**.[26] In this case, the starting 1,1-dihalogenated galactopyranoside is not easily accessible. Interestingly, the

catalytic hydrogen transfer using $RhH(PPh_3)_4$/benzalacetone[27,28] or the couple Shvo's catalyst/cyclohexanone[29] was also successfully used. Overall, these methods require either multistep synthesis or costly reagents. Therefore, other simple and scalable methodologies, not yet explored with galactose, seemed attractive to us.

One of the earliest techniques described for the preparation of δ- or γ-lactones from free carbohydrates is the oxidation by bromine performed in aqueous buffers. This method yields either aldonic acids[30] or lactones.[31] For instance, D-mannono-1,4-lactone was quantitatively synthesized by oxidation of D-mannose with an excess of bromine in the presence of sodium bicarbonate in water.[32] El Ashry et al. explored a microwave-assisted oxidation protocol to prepare D-glucono-1,4-lactone.[33] D-glucose was treated with a large excess of bromine in the presence of calcium chloride and calcium carbonate in water under microwave irradiation. The D-gluconic acid thus formed was then irradiated in methanol with catalytic hydrochloric acid to obtain D-glucono-1,4-lactone (37% yield over two steps). Moreover, oxidation of D-ribose with bromine in the presence of sodium bicarbonate in water was described by Townsend and collaborators.[34] In this case, an excess of bromine was not necessary to form quantitatively D-ribonolactone. After extraction by ethanol, the formed ribonolactone was not isolated, but directly engaged in a protection reaction.

Based on the literature data, we decided to develop a procedure based on bromine oxidation, which had no precedent for D-galactose. Since our goal was the access of lactone **1** in a multigram quantity, we did not follow a procedure using microwave irradiation to avoid scale-up problems.

Oxidation of D-galactose with bromine in the presence of sodium bicarbonate or calcium chloride and carbonate in water was complete in 3 days, regardless of bromine quantity used (1.05 to 3.5 equivalents). The most attractive procedure used 1.05 equivalents of bromine and 2.0 equivalents of bicarbonate (Sch. 1). On a large scale (20 g of D-galactose), we observed that clean reactions require a slow addition of bromine into the galactose solution. The NMR spectra of the crude reaction mixture at the end of the reaction showed only trace amounts of impurities. In some cases, especially on small scales, the NMR data were identical to those of authentic samples. However, purification of lactone **1** happened to be more difficult than expected. Although described



1

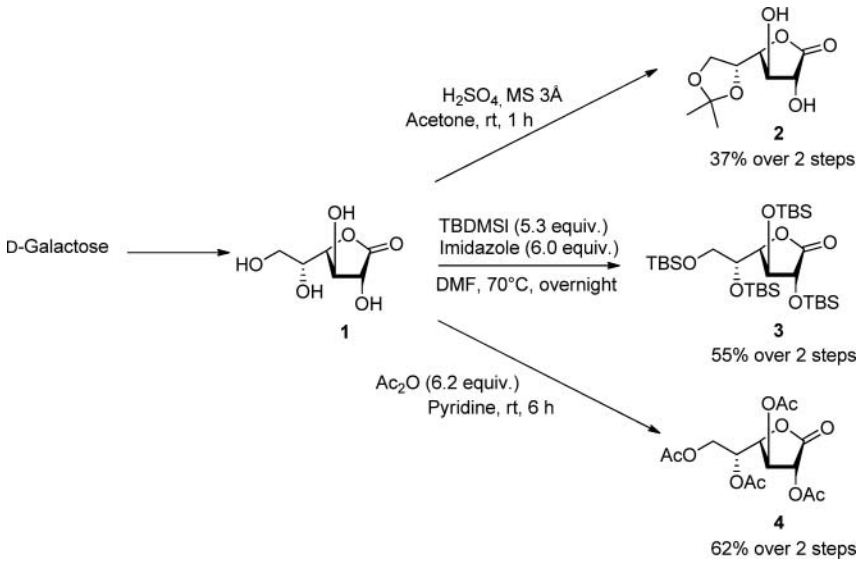
Scheme 1: Synthesis of D-galactono-1,4-lactone.

in the literature on related sugar lactones, the purification by silica gel column chromatography was not satisfactory in terms of yield and/or quality of the final analytical data, whatever the eluent system. Moreover, recrystallization in ethanol or *iso*-propanol did not provide satisfactory yields. Disappointingly, the direct conversion of the crude galactonolactone **1** into acetonide **2** or peracetate **4** was not successful. This lack of reactivity may be due to the presence of salts generated during the oxidation.

Therefore, we developed an extraction procedure to carry on the purification and the derivatization from D-galactonolactone **1**. Choosing an appropriate solvent was essential to extract the product without contaminating salts. D-Galactono-1,4-lactone was poorly soluble in acetone, *iso*-propanol, and acetonitrile. Refluxing the crude mixture in *iso*-propanol led to isomerization into the 1,5-lactone; thus, a mixture of δ- and γ-galactonolactone was obtained. Absolute ethanol was eventually found to be the most efficient extraction solvent. It is important to note that the extraction led to partial formation of the corresponding ethyl ester, even if the mixture was neutralized at pH = 7. An acidic hydrolysis quantitatively afforded the expected compound **1** (Sch. 1). From 20 g of D-galactose we could isolate 18.6 g of **1** following this protocol, which would correspond to a yield of 94%. However, we have to mention that, although NMR data perfectly matched those of authentic lactone **1**, the m.p. value did not correspond to the expected value, thus showing that some inorganic impurities were still present after extraction. On the other hand, the quality of the material was sufficient to allow the derivatization into the key intermediates **2–5** (Sch. 2), for which the yields will be given for two steps from D-galactose. Bases with another countercation that could give a poorly soluble bromide salt and make purification easier were thus considered and the same procedure was reproduced with $KHCO_3$ in place of $NaHCO_3$.[a] However, less intermediate material than expected was recovered and the overall yield was lower.

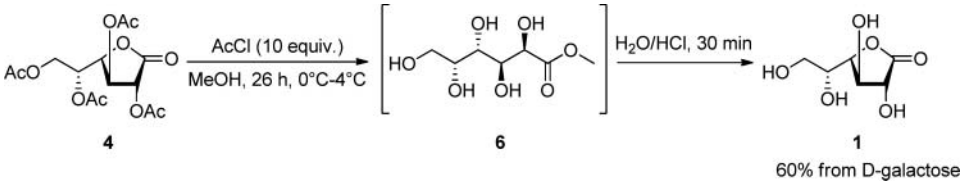
As we have shown previously,[4,19,20] the 5,6-isopropylidene-D-galactonolactone **2** (Sch. 2) is a key intermediate for the generation of conformational probes of enzymatic reactions and inhibitors of therapeutically relevant enzymes. Many conditions can be envisaged to produce **2** from **1**. D-galactono-1,4-lactone **1** can be treated with *iso*-propenyl methyl ether in the presence of *p*-toluenesulfonic acid in DMF,[35] with 2,2-dimethoxypropane in the presence of *p*-toluenesulfonic acid in dry acetone,[16] with 2,2-dimethoxypropane in the presence of Amberlite IR 120 (H+) in DMF,[18] or in the presence of anhydrous copper sulfate or catalytic sulfuric acid in dry acetone.[36,37] Catalysis by anhydrous stannous chloride was also reported with dimethoxypropane in boiling 1,4-dioxane.[23] According to the protocol developed by Toone et al., D-galactonolactone **1** was treated by catalytic

[a]We thank one of the referees for this interesting suggestion.



Scheme 2: Protection reaction from D-galactono-1,4-lactone.

sulfuric acid in dry acetone. We observed that the addition of molecular sieve increased the overall yield (37% over two steps, Sch. 2). Lactone **1** was also persilylated[20] or peracetylated[38] using standard methods, to give, respectively, the protected galactonolactones **3** and **4** in 55% and 62% over two steps (Sch. 2).

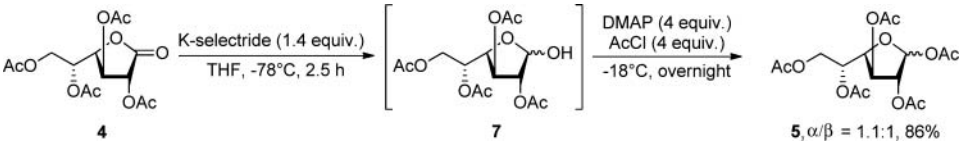


Scheme 3: Synthesis of D-galactono-1,4-lactone.

With peracetate **4** in hand, we addressed the possibility to selectively hydrolyze the four acetates without hydrolyzing the lactone. To do so, we treated compound **4** with acetyl chloride in methanol[39] to provide methyl ester **6**. After acidic hydrolysis, lactone **1** was formed in very high yield (97%). Following this pathway, D-galactono-1,4-lactone **1** could be prepared from D-galactose in 60%, with one intermediate silica gel chromatography purification (Sch. 3), this time with satisfactory analytical data.

Galactofuranosides **7** and **5** are key intermediates for the synthesis of UDP-Gal*f*, the substrate of important enzymes such as UGM and galactofuranosyltransferases.[6,17] Therefore, we also developed a novel procedure for the

selective reduction of the lactone into lactol **7**. The classical procedure relies on a disiamyl borane reduction, using an excess of reducing agent overnight.[17,40] Due to impurities in the commercially available borane and to the large excess required for the completion of this reduction, the purification is tedious and the overall procedure is unsatisfactory. We thus developed a novel procedure using K-selectride in place of disiamyl borane that leads to the same lactol **7** more efficiently and in a shorter time (Sch. 4). The direct one-pot acetylation gave known peracetyl-D-galactofuranose **5** in 86%.



Scheme 4: Synthesis of peracetyl-D-galactofuranose.

CONCLUSION

A new synthesis of D-galactono-1,4-lactone was described, starting from cheap and easily available reagents. Three key galactofuranose derivatives were obtained in two steps on multigram scale with only one purification step. A mild deacetylation methodology afforded pure D-galactono-1,4-lactone and a new method for the reduction of the peracetyl D-galactono-1,4-lactone was developed, giving peracetyl-D-galactofuranose in good yield.

EXPERIMENTAL

All chemicals was purchased in Aldrich Chemicals Co., Acros Chemicals Co., or Alfa Aesar Chemicals Co. and used as purchased. Methanol was distilled over magnesium turnings, THF over sodium/benzophenone and acetone over $MgSO_4$. All reactions were monitored by thin-layer chromatography (TLC) carried out on Merck aluminum roll silica gel 60-F254 using UV light and a molybdate-sulfuric acid solution as revelator. ^1H and ^{13}C NMR spectra were recorded on a JEOL (JNM EX-400). All compounds were characterized by ^1H and ^{13}C NMR as well as by ^1H-^1H and ^1H-^{13}C correlation experiment when necessary. The following abbreviations were used to describe the multiplicities: s = singlet, d = doublet, t = triplet, m = multiplet, br = broad, and br s = broad singlet. The numbering of the protons and carbons is analogous to the proton numbers resulting from the name of the compound. Aromatic, benzyl, acetyl, and methyl (carbons and protons) are respectively labeled with "arom," "Bn," "Ac," and "Me" subscript; quaternary carbons are indicated with a "q" subscript. Chemical shifts (δ) are reported in ppm and referenced indirectly to

TMS via the solvent (or residual solvent) signals. Merck silica gel (60 mesh, particle size 0.040–0.063 mm) was employed for flash column chromatography using technical solvent distilled prior to use as eluting systems.

D-galactono-1,4-lactone (1)

D-galactose (20 g, 111 mmol, 1.0 equiv.) and sodium bicarbonate (18.6 g, 222 mmol, 2.0 equiv.) were dissolved in water (100 mL). Bromine (6 mL, 116.6 mmol, 1.05 equiv.) was slowly added dropwise at 0°C, and the resulting solution was stirred 3 d at rt. Sodium bisulfite (580 mg, 11 mmol, 0.1 equiv.) was added to quench the remaining bromine. After 10 min, the solution was concentrated and dried in vacuo. The remaining solid was extracted by absolute ethanol (3 × 200 mL) under vigorous stirring or sonication, followed by filtration on Celite. The remaining ethanolic phases were concentrated and dried. The remaining solid was hydrolyzed by acidic water (3 × 100 mL, 0.4 mL of concentrated HCl per 100 mL) during 30 min, concentrated, and dried under oil pump vacuum, to give **1** as a solid (18.6 g) that was used such as for further derivatizations. The analytical data were identical to the data of the commercial compound. ^{1}H NMR (400 MHz, D_2O): δ = 4.50 (m, 1H; H-2), 4.27–4.19 (m, 2H; H-3 H-4), 3.83–3.78 (m, 1H; H-5), 3.62–3.56 (m, 2H; H-6). ^{13}C NMR (101 MHz, D_2O): δ = 176.0 (C-1), 80.0 (C-4), 73.7 (C-2), 72.8 (C-3), 68.9 (C-5), 62.0 (C-6).

5,6-*O*-isopropylidene-D-galactono-1,4-lactone (2)

D-galactono-1,4-lactone 1 (18.6 g) and activated 3Å molecular sieve (8.4 g) were dissolved under argon in dry acetone (740 mL); 0.2 mL of concentrated sulfuric acid were added, and the solution was stirred 1 h at rt. The solution was neutralized by sodium biocarbonate (20 g) and stirred 30 min, then filtrated on Celite and concentrated. The residue was purified by flash chromatography (cyclohexane/ethyl acetate 4:6) to give the expected product (9.0 g, 37% over two steps). The analytical data were identical to the literature data.[16,37] ^{1}H NMR (400 MHz, $CDCl_3$): δ = 4.63 (br s, 2H; 2 OH), 4.53 (d, $J_{2\text{-}3}$ = 8.3 Hz, 1H; H-2), 4.35 (m, 2H; H-3, H-5), 4.21 (dd, J = 7.6 Hz, J = 3.9 Hz, 1H; H-4), 4.14 (ABX, $J_{6a\text{-}6b}$ = 8.5 Hz, $J_{6a\text{-}5}$ = 6.9 Hz, 1H; H-6a), 4.01 (ABX, $J_{6a\text{-}6b}$ = 8.7 Hz, $J_{6b\text{-}5}$ = 6.4 Hz, 1H; H-6b), 1.41, 1.37 (2 s, 6H; 2 CH_3). ^{13}C NMR (100 MHz, $CDCl_3$): δ = 174.6 (C-1), 110.4 (O-C-O), 79.8 (C-4), 74.6, 74.2, 74.1 (C-2, C-3, C-5), 65.0 (C-6), 26.0, 25.3 (2 CH_3).

2,3,5,6-Tetra-*O*-*tert*-butyldimethylsilyl-D-galactono-1,4-lactone (3)

D-galactono-1,4-lactone **1** (24.8 mmol) was dissolved in dry DMF (65.0 mL). Imidazole (10.1 g, 148 mmol, 6.0 equiv.) and *tert*-butyldimethylsilyl chloride

(19.74 g, 131 mmol, 5.3 equiv.) were added under argon. The resulting solution was then heated at 70°C overnight, and diluted with diethylether (200 mL) and water (20 mL). The organic layer was washed with brine, dried over $MgSO_4$, filtrated, and concentrated. The residue was purified by flash chromatography (cyclohexane/ethyl acetate 40:1) to afford the expected compound (8.6 g, 55%). The analytical data were comparable to the data of the literature.[20] $[\alpha]_D^{23}$ –11.4 (c 1.0, $CHCl_3$). m.p. 49–50°C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 4.45 (t, $J_{2\text{-}3} = J_{3\text{-}4}$ = 6.1 Hz, 1H; H-3), 4.38 (d, $J_{2\text{-}3}$ = 6.1 Hz, 1H; H-2), 4.35 (dd, $J_{4\text{-}3}$ = 6.1 Hz, $J_{4\text{-}5}$ = 1.7 Hz, 1H; H-4), 3.85 (ddd, $J_{5\text{-}4}$ = 1.7 Hz, $J_{5\text{-}6b}$ = 5.8 Hz, $J_{5\text{-}6a}$ = 7.7 Hz, 1H; H-5), 3.70 (ABX, $J_{6a\text{-}6b}$ = 9.7 Hz, $J_{6a\text{-}5}$ = 7.7 Hz, 1H; H-6a), 3.66 (ABX, $J_{6b\text{-}6a}$ = 9.7 Hz, $J_{6b\text{-}5}$ = 5.8 Hz, 1H; H-6b), 0.95 (s, 9H; Si-*t*Bu), 0.92 (s, 9H; Si-*t*Bu), 0.91 (s, 9H; Si-*t*Bu), 0.90 (s, 9H; Si-*t*Bu), 0.23 (s, 3H; Si-Me), 0.18 (s, 3H; Si-Me), 0.16 (s, 3H; Si-Me), 0.15 (s, 3H; Si-Me), 0.14 (s, 3H; Si-Me), 0.11 (s, 3H; Si-Me), 0.09 (s, 6H; Si-Me). ^{13}C NMR (100 MHz, $CDCl_3$) : δ = 173.5 (C-1), 81.5 (C-4), 76.9 (C-2), 75.6 (C-3), 71.5 (C-5), 63.0 (C-6), 25.8, 25.8, 25.7, 25.6 (4 Si-C(CH_3)$_3$), 18.2, 18.2, 18.1, 17.8 (4 Si-*C*(CH_3)$_3$), –3.4, –4.1, –4.2, –4.3, –4.7, –4.9, –5.4, –5.5 (8 Si-Me). MS (DIC-NH_3): m/z 652 $[M + NH_4]^+$. Elemental analysis for $C_{30}H_{66}O_6Si_4$: calcd(%): C 56.73 H 10.47. found: C 56.87 H 10.58.

2,3,5,6-Tetra-*O*-acetyl-D-galactono-1,4-lactone (4)

D-galactono-1,4-lactone (11.1 mmol) was dissolved under argon in pyridine (20 mL) and the mixture was sonicated 2 min. Acetic anhydride (65 mL, 69.0 mmol, 6.15 equiv.) was then added at 0°C, and the resulting solution was stirred 6 h at rt and dropped on ice (40 g). Ethyl acetate (50 mL) was added. The organic layer was washed with HCl 10% solution (2 × 50 mL) and brine (50 mL), dried on $MgSO_4$, and concentrated in vacuo. The residue was purified by flash chromatography (cyclohexane/ethyl acetate 1:1) to give the expected product as a white solid (2.37 g, 62% over two steps). The analytical data were comparable to the data of the literature.[38] $[\alpha]_D^{20}$ –12.1 (c 1.0, $CHCl_3$). m.p. 70°C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 5.60 (d, $J_{2\text{-}3}$ = 7.0 Hz, 1H; H-2), 5.42 (t, $J_{2\text{-}3} = J_{3\text{-}4}$ = 7.0 Hz, 1H; H-3), 5.32 (ddd, $J_{5\text{-}6a}$ = 6.4 Hz, $J_{5\text{-}6b}$ = 5.5 Hz, $J_{5\text{-}4}$ = 2.8 Hz, 1H; H-5), 4.59 (dd, $J_{4\text{-}3}$ = 6.8 Hz, $J_{4\text{-}5}$ = 2.8 Hz, 1H; H-4), 4.32 (ABX, $J_{6b\text{-}6a}$ = 11.9 Hz, $J_{6b\text{-}5}$ = 5.5 Hz, 1H; H-6b), 4.23 (ABX, $J_{6a\text{-}6b}$ = 11.9 Hz, $J_{6a\text{-}5}$ = 6.4 Hz, 1H; H-6a), 2.18 (s, 3H; Ac), 2.15 (s, 3H; Ac), 2.11 (s, 3H; Ac), 2.07 (s, 3H; Ac). ^{13}C NMR (101 MHz, $CDCl_3$): δ = 170.3 (C=O), 169.7 (C=O), 169.6 (C=O), 169.3 (C=O), 168.0 (C-1), 77.3 (C-4), 72.2 (C-3), 71.9 (C-2), 68.2 (C-5), 61.6 (C-6), 20.6, 20.5, 20.3 (4 Ac). MS (ESI-Na): m/z 369 $[M + Na]^+$. HRMS for $C_{14}H_{18}O_{10}Na$: calcd: 369.0798. found: 369.0812.

D-galactono-1,4-lactone (1) from 4

The 2,3,5,6-tetra-O-acetyl-D-galactono-1,4-lactone **4** (2.37 g, 6.84 mmol, 1.0 equiv.) was dissolved under argon in dry methanol (150 mL) at 0°C. Acetyl

chloride (4.9 mL, 68.4 mmol, 10.0 equiv.) was added dropwise and the solution was stirred at 0°C during 8 h and 18 h at 4°C. The solution was then concentrated, hydrolyzed by acidic water (2 × 50 mL, 0.4 mL of concentrated HCl per 100 mL) during 30 min, concentrated, and dried in vacuo to afford D-galactono-1,4-lactone **1** (1.19 g, 97%).

1,2,3,5,6-Penta-*O*-acetyl-D-galactofuranose (5)

The 2,3,5,6-tetra-*O*-acetyl-D-galactono-1,4-lactone **4** (400 mg, 1.16 mmol, 1.0 equiv.) was dissolved in dry THF (2.5 mL) under argon. K-selectride (1M in THF, 1.16 mL, 1.16 mmol, 1.0 equiv.) was slowly added at –78°C and the mixture was stirred during 1 h. After a first addition of K-selectride (0.25 mL, 0.25 mmol, 0.22 equiv.), the mixture was stirred during 45 min, followed by a second addition of K-selectride (0.25 mL, 0.25 mmol, 0.22 equiv.). Forty-five minutes after this addition, DMAP (565 mg, 4.62 mmol, 4 equiv.) and acetyl chloride (0.33 mL, 4.62 mmol, 4 equiv.) were added. The resulting solution was warmed to 0°C, maintained at this temperature during 45 min, and stirred overnight at –18°C. The excess of acetyl chloride was neutralized with a saturated solution of ammonium chloride (10 mL) at 0°C. After extraction with dichloromethane, the organic layer was dried over $MgSO_4$, filtrated, and concentrated under vacuo. The residue was purified by silica gel chromatography (cyclohexane/ethyl acetate 3:1) to afford the expected compound (388 mg, 86%, α/β: 1.1:1). The analytical data were comparable to those of the literature.[13] ^{1}H NMR (400 MHz, $CDCl_3$): δ = 6.33 (d, $J_{1\text{-}2} = 4.8$ Hz, 1H; H-1$_\alpha$), 6.19 (s, 1H; H-1$_\beta$), 5.55 (t, $J_{2\text{-}3} = J_{3\text{-}4} = 6.6$ Hz, 1H; H-3$_\alpha$), 5.38–5.25 (m, 3H; H-2$_\alpha$, H-5$_\alpha$, H-5$_\beta$), 5.19 (d, $J_{2\text{-}3} = 2.0$ Hz, 1H; H-2$_\beta$), 5.09 (dd, $J_{3\text{-}4} = 5.4$ Hz, $J_{3\text{-}2} = 2.0$ Hz, 1H; H-3$_\beta$), 4.38–4.13 (m, 6H; H-4$_\alpha$, H-4$_\beta$, H-6a$_\alpha$, H-6a$_\beta$, H-6b$_\alpha$,H-6b$_\beta$), 2.14–2.10 (m, 18H; 3 Ac$_\alpha$, 3 Ac$_\beta$), 2.09 (s, 3H; Ac$_\alpha$), 2.08 (s, 3H; Ac$_\alpha$), 2.08 (s, 6H; 2 Ac$_\beta$). ^{13}C NMR (101 MHz, $CDCl_3$): δ = 170.5 (C=O Ac$_\beta$), 170.4 (C=O Ac$_\alpha$), 170.0 (C=O Ac$_\beta$), 169.9 (C=O$_\alpha$), 169.8 (C=O$_\alpha$), 169.8 (C=O$_\alpha$), 169.7 (C=O$_\beta$), 169.4 (C=O$_\beta$), 169.3 (C=O$_\alpha$), 169.0 (C=O$_\beta$), 99.1 (C-1$_\beta$), 93.0 (C-1$_\alpha$), 82.1 (C-4$_\beta$), 80.6 (C-2$_\beta$), 79.0 (C-4$_\alpha$), 76.3 (C-3$_\beta$), 75.3 (C-2$_\alpha$), 73.3 (C-3$_\alpha$), 70.3 (C-5$_\alpha$), 69.2 (C-5$_\beta$), 62.5 (C-6$_\beta$), 62.1 (C-6$_\alpha$), 21.0, 20.9, 20.8, 20.8, 20.7, 20.7, 20.6, 20.5 (5 Ac$_\alpha$, 5 Ac$_\beta$).

ACKNOWLEDGEMENT

This work was funded by FNRS (“Mandat d’Impulsion Scientifique” F.4502.09, FRFC grant 2.4.625.08.F, “Crédit au chercheur” 1.5.167.10 and F.R.I.A., Fonds pour la Formation à la Recherche dans l’Industrie et dans l’Agriculture) and by the Académie Louvain (A.R.C. 08/13-012).

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