Graphical Abstract

Oxidative reactions of sulfinyl dienes as an entry to functionalized carbohydrate-like products and furans

Alejandro Castellanos, Iñaki Osante, Jorge Fernández, Roberto Fernández de la Pradilla* and Alma Viso*
Instituto de Química Orgánica General. Consejo Superior de Investigaciones Científicas (IQOG-CSIC). Juan de la Cierva 3, 28006 Madrid (Spain).

Leave this area blank for abstract info.

Oxidative reactions of sulfinyl dienes as an entry to functionalized carbohydrate-like products and furans

Alejandro Castellanos, Iñaki Osante, Jorge Fernández, Roberto Fernández de la Pradilla* and Alma Viso*

Instituto de Química Orgánica General. Consejo Superior de Investigaciones Científicas (IQOG-CSIC).

Juan de la Cierva 3, 28006 Madrid (Spain)

ABSTRACT: Oxidative cleavage ($\text{OsO}_4/\text{NaIO}_4$) of a monoprotected dihydroxy sulfinyl diene affords a lactol, readily transformed into a sulfinyl pyranose. Alternatively, base promoted intramolecular cyclization of a lactol derived carbamate to a bicyclic oxazolidinone followed by simple transformations leads to an amino sulfonyl pyranose. In contrast, ozonolysis of a variety of hydroxy sulfinyl dienes leads to fair yields of 3-sulfinyl furans in a single step.

Keywords: sulfoxides, pyranoses, furans, oxidation, sulfones

The development of synthetic methodologies that rely on enantiopure sulfoxides remains an active area of research.^{1,2} In connection with our long standing involvement in this field,³ we undertook studies directed to prepare unusual lactols and carbohydrate-like products such as **B** or **C** from readily available hydroxy sulfinyl dienes **A** (Scheme 1).^{4,5} At the inception of this research, we considered that oxidative cleavage of dienyl sulfoxides **A** should produce sulfinyl lactols **B** that upon functionalization and hydroxyl deprotection should lead to pyranose derivatives such as **C**. In this paper, we describe our efforts on the oxidative cleavage of dienes **A** to afford lactols **B** and subsequent transformation to pyranoses **C**. In addition, the serendipitous finding of small amounts of a functionalized sulfinyl furan **D** while seeking an efficient

deprotection of a particular lactol **B** led us to briefly examine the oxidative cleavage of simple hydroxyl sulfinyl dienes **E** by ozonolysis to produce fair yields of sulfinyl furans **D**.

Scheme 1. Proposed approach to furans and carbohydrate-like products.

Readily available 1-sulfinyl diene **1**,⁶ as an *E/Z* mixture, was lithiated (LDA, THF) and trapped with (*S*)-2-*t*-butyldimethylsilyloxypropionaldehyde,⁷ providing α -hydroxy sulfinyl diene **2a** with a 90:10 diastereomeric ratio. Remarkably, the additional carbon-oxygen stereocenter of silylated lactaldehyde allowed for a diastereomeric ratio higher than the expected for these reactions.⁸ At this stage we examined briefly our metal-catalyzed oxidation-epoxidation protocol on **2a** that could lead to a sulfonyl oxirane at positions 4 and 5.^{4a} Unfortunately, the reaction led to inseparable mixtures of the intermediate hydroxy dienyl sulfone related to **2a** and the desired oxirane. Since this methodology was not viable in this case, presumably due to steric hindrance, we turned our attention to a dihydroxylation/cleavage protocol. In this manner, treatment of **2a** with OsO₄ and Me₃NO produced sulfinyl triol **3** (66%) and sulfonyl triol **4** (15%), both as mixture of diastereomers. Independent treatment of **3** and **4** with NaIO₄ led to the oxidative cleavage giving the corresponding lactols with good yields (94% for **5** and 77% for **6**). Direct treatment of lactol **5**

with TBAF and AcOH triggered the desilylation and ring expansion to furnish sulfinyl pyranose **7**, 65% yield, as an anomeric mixture.

Scheme 2. Synthetic routes to carbohydrate-like products from α -hydroxy sulfinyl diene **2a**.

At this stage, to access amino carbohydrate precursors,⁹ we examined the introduction of a nitrogen based nucleophile by formation of a carbamate and intramolecular Michael addition.^{10,11,12} Thus, lactols **5** and **6** were independently treated with benzyl isocyanate providing anomeric mixtures of carbamates **8** (83:17) and **9** (80:20) in 67% and 72% yields respectively and these were further submitted to base induced intramolecular Michael addition rendering, after chromatography, diastereomerically pure bicyclic oxazolidinones (3a*S*,6a*R*)-**10** (56%), along with diastereomer (3a*R*,6a*S*)-**10'** and **11** (80%), respectively. At this point, we examined conversion of **10** into **11** by oxidation at sulfur with MMPP that smoothly produced sulfonyl oxazolidinone **11** in 92% yield. Desilylation, carbamate cleavage and ring expansion with methanolic HCl,¹³ followed by mild basic treatment rendered amino sulfonyl pyranose **12** (63%) as a mixture of anomers.

Finally, we attempted to transform oxazolidinone **10** directly into an amino carbohydrate precursor through a Pummerer protocol.¹⁴ Thus, reaction of **10** with TFAA in benzene produced ketone **14** and vinyl sulfide **13** as an inseparable 50:50 mixture, the latter probably formed by β -elimination of the Pummerer intermediate. Subsequent diastereoselective reduction of ketone **14**, in the mixture, with NaBH₄ in EtOH afforded hydroxy bicyclic oxazolidinone **15** (42% isolated yield from **10**) along with unreacted **13** (36%).

Structural determination for the above compounds was based on NMR data. In particular, NOE experiments allow for the stereochemical elucidation of diastereomeric bicyclic oxazolidinones (3a*S*,6a*R*)-**10**, (3a*R*,6a*S*)-**10'** and **15** as well as pyranose **12** (Figure 1). In particular, for compounds **10** and **15** strong signal enhancements of H_{6a} were observed upon irradiation of H_{3a} showing a *cis* relationship. Also, the major diastereoisomer (3a*S*,6a*R*)-**10** along with **15** display NOE between H₆/H_{6a} and H₆/H_{1'}, while minor (3a*R*,6a*S*)-**10'** lacks signal enhancement between H_{6a} and H₆ which places the oxazolidinone ring at the β face for this isomer. Finally, a *cis* arrangement of H₃, H₄, H₅ and Me could be established for pyranose **12** from the NOE experiment.

Figure 1. Nuclear Overhauser effects measured for compounds **10**, **12** and **14**.

Attempted deprotection of lactol **5** with TMSI led to low yields of functionalized sulfinyl furan **16a** (Scheme 3), instead of the desired pyranose **7** (Scheme 2). This somewhat unexpected result attracted our attention to the preparation of furans. Polysubstituted furans represent an important class of five-membered heterocycles frequent structural elements of many natural products (kalkolides, combranolides, pheromones, etc.) and pharmaceutically significant substances (polyether antibiotics).¹⁵ Furthermore, furans are relatively highly reactive heteroaromatic compounds that can be employed as useful intermediates¹⁶ in synthetic chemistry, as building blocks for a large number of heterocyclic compounds and in natural products synthesis.¹⁷ Therefore, a substantial number of approaches to substituted furans are known.¹⁸ The most frequently used methods include the cyclocondensation of 1,4-dicarbonyl compounds (Paal-Knorr synthesis)¹⁹ and the classical Feist-Benary synthesis.²⁰ Nonetheless, the development of new and more efficient methods for the synthesis of highly functionalized furans under mild conditions remains an area of ongoing interest. In particular, 3-sulfinyl furans are useful directing elements in asymmetric Diels-Alder reactions, allylations and alkylations of remote functionalities.²¹

Scheme 3. Attempted deprotection of lactol **5**.

Considering that ozonolysis of hydroxy vinyl oxiranes was an adequate route to lactols,^{4a} we chose to examine if these conditions were adequate to access lactols **5** directly from simpler hydroxy sulfinyl dienes **2**, in a shorter sequence than the dihydroxylation/fragmentation protocol. Furthermore, the possibility of transforming lactols such as **5** into sulfinyl furans **16** (Scheme 3) was appealing since this route would constitute a new entry into 3-sulfinyl furans. In an unexpected result, even under carefully controlled conditions and with a reductive work-up, the ozonolysis of these sulfinyl dienes led directly to the sulfinyl furans in fair yields.

Table 1 summarizes our results in this chemistry with different optically pure α -hydroxy sulfinyl dienes that were prepared in two steps from menthyl sulfinate. In all cases, the ozonolysis was carried out at -78°C in CH_2Cl_2 after the exposure of the dienes to O_2 for 10 min. In the first two experiments with α -hydroxy sulfinyl diene (*S,S*)-**2b**, O_3 was slowly bubbled through the solution for 30 min (entry 1) and 15 min (entry 2) affording mixtures of sulfinyl furan **16b** and sulfonyl furan **17b** in low yields. In view of these results, we decided to reduce the time of exposure to O_3 but using a higher flow until the saturated solution turned pale blue. This process took between 5-10 minutes in all cases and the reactions were monitored by TLC and finally quenched with SMe_2 rendering selectively 3-sulfinyl furan **16b** (70%) (entry 3). Diastereomeric α -hydroxy sulfinyl diene (*R,S*)-**2b** also reacted under analogous conditions (entry 4), however sulfinyl furan **16b** was isolated with moderate yield (52%) along with sulfonyl furan **17b** (13%).

Table 1. Ozonolysis of α -hydroxy sulfinyl dienes **2**.

Entry	Substrate	R ¹ /R ²	t (min)	16 (Yield)	17 (Yield)
1	(S,S) - 2b	Et/H	30	16b (8%)	17b (10%)
2	(S,S) - 2b	Et/H	15	16b (15%)	17b (5%)
3	(S,S) - 2b	Et/H	5	16b (70%)	-
4	(R,S) - 2b	Et/H	5	16b (52%)	17b (13%)
5	(S,S) - 2c	<i>i</i> -Pr/H	5	16c (73%)	-
6	2d^a	<i>t</i> -Bu/H	10	16d (63%)	17d (11%)
7	2d^a	<i>t</i> -Bu/H	30	16d (72%)	17d (15%)
8	(SS,RR) - 2e^b	<i>p</i> -FC ₆ H ₄ /H	10	16e (59%)	-
9	2f	CH ₂ =CH/H	5	16f^c	-
10	2g^a	CH ₂ OTBDPS/H	5	16g (56%)	
11	2h^{a,b}	Et/Me	3	16h (52%)	17h (18%)

^a A mixture of (S,S) and (R,S) diastereomers of **2** was submitted to ozonolysis. ^b A racemic mixture of **2** was used. ^c Decomposition of the starting material was observed in the TLC and NMR of the crude product.

Similarly, dienes with bulkier alkyl substituents **2c** (R¹ = *i*-Pr) and **2d** (R¹ = *t*-Bu) afforded sulfinyl furans **16c**, **16d** in good yields (entries 5-7), along with minor amounts of sulfonyl furan **17d** (11-15%, entries 6, 7). Aromatic substrate **2e** (R¹ = *p*-FC₆H₄) afforded furan **16e** in moderate yield after 10 min of ozonolysis (entry 8). Enantiopure sulfinyl-substituted furfural **16f** (R¹ = CHO) has been previously synthesized from 3-bromofuran and optically pure menthyl *p*-toluenesulfinate using lithiation chemistry.^{21e,f} Thus, we planned to prepare this interesting intermediate hoping that a double ozonolysis starting from triene **2f** could achieve this goal. However, only decomposition of the starting material was observed by TLC and NMR of the crude product (entry 9). More functionalized hydroxy sulfinyl diene **2g** afforded the expected sulfinyl

furan **16g** in moderate 56% yield but without formation of the corresponding sulfone (entry 10). We finally decided to address the introduction of an additional substituent in the heterocyclic ring. Thus, diene **2h** with a methyl group in the internal position ($R^2 = \text{Me}$) afforded trisubstituted furan **16h** (52%) with a Me group at the 5-position of the ring. In this case sulfonyl furan **17h** (18%) was also isolated after purification (entry 11).

To conclude, we have explored the reactivity of α -hydroxy sulfinyl dienes under oxidative conditions. The use of $\text{OsO}_4/\text{NaIO}_4$ on a monoprotected dihydroxy sulfinyl diene **2a** affords lactol **5**, that can be transformed into sulfinyl pyranose **7**, or into amino sulfonyl pyranose **12** by intramolecular Michael addition of carbamate **8** and functional group manipulation. In contrast, ozonolysis of a variety of hydroxy sulfinyl dienes **2** leads to fair yields of 3-sulfinyl furans **16** in a single step. In spite of the interesting results described herein, the lack of time and resources prevented us from carrying out further research on these topics.

Experimental

Materials and methods

All reactions were carried out under a positive pressure of dry argon, using freshly distilled solvents under anhydrous conditions. Et_2O and THF were distilled from sodium and benzophenone, CH_2Cl_2 was distilled from CaH_2 . ^1H and ^{13}C NMR spectra were recorded Varian INOVA-300 (300/75 MHz), and Varian INOVA-400 (400/100 MHz) using CDCl_3 as solvent and with the residual solvent signal as internal reference. Melting points were determined on a Reichert Kofler microscope and are uncorrected. Optical rotations were measured on a Perkin-Elmer 241 polarimeter at 20 °C using a sodium lamp and in CHCl_3 solution. Infrared spectra (IR) were obtained on a Perkin-Elmer 681 and on a Perkin-Elmer Spectrum one. Low resolution mass spectra were recorded by direct injection on a Hewlett Packard 5973 MSD instrument using the electronic impact technique with an ionization energy of 70 eV (EI) or on a Hewlett Packard 1100 MSD instrument using the atmospheric pressure chemical ionization (APCI) or electrospray (ES) chemical

ionization techniques in its positive or negative modes. Compounds *E/Z*-**1**,⁶ **2b-f** and **2h** have already been described.⁸

General procedure for the synthesis of hydroxy sulfinyl dienes **2**.

A round-bottomed flask was charged with THF (3.5 mL/mmol) and 2.6 equiv of freshly distilled *i*-Pr₂NH, and cooled to -78 °C. To the above solution was added 2.5 equiv of *n*-BuLi and the resulting LDA solution (*ca.* 0.3 M) was stirred at this temperature. After 10 min a solution of 1 equiv of a 40:60 *E/Z* mixture of dienyl sulfoxides **1** in THF (2 mL/mmol), previously dried over 4 Å sieves, was added dropwise slowly (*ca.* 8 min/mmol of sulfoxide) to produce a pale yellow solution. After stirring for an additional 10 min at -78 °C, 3-5 equiv of freshly distilled aldehyde was added dropwise and the resulting colorless solution was stirred at this temperature for 10 min. The reaction mixture was quenched with a saturated solution of NH₄Cl (2 mL/mmol) and H₂O (2 mL/mmol), diluted with EtOAc (3 mL/mmol) and the layers were separated. The aqueous layer was extracted with EtOAc (3 times, 4 mL/mmol). The combined organic extracts were washed with a saturated solution of NaCl (4 mL/mmol), dried over MgSO₄ and concentrated under reduced pressure to give a crude product that was purified by column chromatography using the appropriate mixture of eluents.

Synthesis of (+)-(2*S*,*S*_S)-(3*E*)-1-(*t*-Butyldiphenylsilyloxy)-3-(*p*-toluenesulfinyl)hexa-3,5-dien-2-ol, **2g**, and (+)-(2*R*,*S*_S)-(3*E*)-1-(*t*-Butyldiphenylsilyloxy)-3-(*p*-toluenesulfinyl)hexa-3,5-dien-2-ol, **2g'**.²²

From a solution of the 40:60 mixture of sulfinyl dienes *E/Z*-**1** (843 mg, 4.38 mmol) in 20 mL of THF, 2.0 equiv of LDA and a solution of *t*-butyldiphenylsilyloxyacetaldehyde (3.93 g, 13.15 mmol) in 16.6 mL of THF, following the general procedure, a 34:66 mixture of hydroxy sulfinyl dienes **2g'** and **2g** was obtained. Chromatographic purification (0-10% EtOAc-CH₂Cl₂), gave **2g'** (622 mg, 28%), **2g** (806 mg, 38%) and 225 mg (10%) of the mixture of the two diastereomers.

Data for **2g**: $R_f = 0.08$ (35% EtOAc-CH₂Cl₂). $[\alpha]^{20}_D = +131.8$ ($c = 9.30$). **¹H NMR (300 MHz)-COSY** δ 0.97 (s, 9 H, 3 CH₃ TBDPS), 2.34 (s, 3 H, CH₃ *p*Tol), 2.78 (d, 1 H, $J = 2.6$ Hz, OH), 3.14 (dd, 1 H, $J = 10.6, 8.9$ Hz, H-1), 3.26 (dd, 1 H, $J = 10.5, 4.3$ Hz, H-1), 4.63 (ddd, 1 H, $J = 8.9, 4.3, 2.7$ Hz, H-2), 5.33 (dd, 1 H, $J = 10.0, 1.7$ Hz, H-6_E), 5.48 (dd, 1 H, $J = 16.8, 1.7$ Hz, H-6_Z), 6.53 (ddd, 1 H, $J = 16.7, 11.4, 10.0$ Hz, H-5), 6.88 (d, 1 H, $J = 11.4$ Hz, H-4), 7.16 (d, 2 H, $J = 8.5$ Hz, 2 H_{*m*} *p*Tol), 7.34-7.55 (m, 12 H, 4 H_{*o*}, 4 H_{*m*}, 2 H_{*p*} TBDPS, 2 H_{*o*} *p*Tol). **¹³C NMR (75 MHz)-HSQC** δ 19.1 (C TBDPS), 21.5 (CH₃ *p*Tol), 26.7 (3 CH₃ TBDPS), 66.9 (C-1), 70.1 (C-2), 124.4 (C-6), 125.9 (2 C_{*o*} *p*Tol), 127.7 (2 C_{*m*} TBDPS), 127.8 (2 C_{*m*} TBDPS), 128.3 (C_{*p*} TBDPS), 129.8 (2 C_{*m*} *p*Tol), 129.9 (C_{*p*} TBDPS), 130.6 (C-5), 132.5 (C-4), 132.7 (C_{*ipso*} TBDPS), 132.8 (C_{*ipso*} TBDPS), 135.4 (2 C_{*o*} TBDPS), 135.5 (2 C_{*o*} TBDPS), 140.3 (C_{*ipso*} *p*Tol), 141.8 (C-3), 143.2 (C_{*p*} *p*Tol). **IR** (film): 3429, 3065, 3043, 2929, 2856, 1631, 1591, 1471, 1427, 1113, 1029, 932, 808, 740 cm⁻¹. **MS** (ES): 1003 [2 M+Na]⁺, 513 [M+Na]⁺, 491 [M+H]⁺ (100%).

Data for **2g'**: $R_f = 0.13$ (35% EtOAc-CH₂Cl₂). $[\alpha]^{20}_D = +105.9$ ($c = 8.50$). **¹H NMR (300 MHz)** δ 1.01 (s, 9 H, 3 CH₃ TBDPS), 2.34 (s, 3 H, CH₃ *p*Tol), 2.91 (d, 1 H, $J = 2.2$ Hz, OH), 3.43 (dd, 1 H, $J = 10.4, 4.0$ Hz, H-1), 3.68 (dd, 1 H, $J = 10.4, 9.2$ Hz, H-1), 4.56 (ddd, 1 H, $J = 9.2, 4.0, 2.2$ Hz, H-2), 5.33 (dd, 1 H, $J = 10.1, 1.1$ Hz, H-6_E), 5.48 (dd, 1 H, $J = 16.8, 1.1$ Hz, H-6_Z), 6.43 (ddd, 1 H, $J = 16.7, 11.3, 9.9$ Hz, H-5), 6.93 (d, 1 H, $J = 11.4$ Hz, H-4), 7.20 (d, 2 H, $J = 7.9$ Hz, 2 H_{*m*} *p*Tol), 7.31-7.61 (m, 12 H, 4 H_{*o*}, 4 H_{*m*}, 2 H_{*p*} TBDPS, 2 H_{*o*} *p*Tol). **¹³C NMR (75 MHz)** δ 18.9 (C TBDPS), 21.2 (CH₃ *p*Tol), 26.6 (3 CH₃ TBDPS), 67.0 (C-1), 69.6 (C-2), 124.4 (C-6), 125.4 (2 C_{*o*} *p*Tol), 127.5 (C_{*p*} TBDPS), 127.6 (4 C_{*m*} TBDPS), 129.5 (2 C_{*m*} *p*Tol), 129.7 (C_{*p*} TBDPS), 130.5 (C-5), 132.6 (C_{*ipso*} TBDPS), 132.7 (C_{*ipso*} TBDPS), 133.5 (C-4), 135.3 (4 C_{*o*} TBDPS), 140.6 (C_{*ipso*} *p*Tol), 141.2 (C-3), 142.9 (C_{*p*} *p*Tol). **IR** (film): 3350, 3071, 3050, 2957, 2930, 2858, 1590, 1491, 1472, 1463, 1428, 1391, 1362, 1304, 1186, 1112, 1047, 1013, 928, 809, 740 cm⁻¹. **MS** (ES): 513 [M+Na]⁺, 491 [M+H]⁺ (100%).

Synthesis of (+)-(2*S*,3*R*,5*S*)-(4*E*)-2-(*t*-Butyldimethylsilyloxy)-4-(*p*-toluenesulfinyl)hepta-4,6-dien-3-ol, 2a', and (+)-(2*S*,3*S*,5*S*)-(4*E*)-2-(*t*-Butyldimethylsilyloxy)-4-(*p*-toluenesulfinyl)hepta-4,6-dien-3-ol, 2a.

From a solution of the 40:60 mixture of sulfinyl dienes *E/Z*-**1** (573 mg, 2.98 mmol) in 12 mL of THF, 2.0 equiv of LDA and a solution of freshly prepared (*S*)-2-*t*-butyldimethylsilyloxypropionaldehyde (1.68 g, 8.94 mmol) in 13.4 mL of THF, following the general procedure, a 10:90 mixture (lower ratios of **2a** were obtained when temperature and stirring was not carefully controlled) of hydroxy sulfinyl dienes **2a'** and **2a** was obtained. Chromatographic purification (10-40% EtOAc-hexane), gave **2a'** (110 mg, 9%) and **2a** (740 mg, 65%) as colorless oils. About 8% of the optically pure aldehyde was recovered during the purification. Data for **2a'**: R_f = 0.26 (30% EtOAc-hexane). $[\alpha]^{20}_D$ = +121.3 (c = 2.30). $^1\text{H NMR}$ (300 MHz) δ 0.08 (s, 3 H, TBDMS), 0.09 (s, 3 H, TBDMS), 0.88 (s, 9 H, TBDMS), 1.10 (d, 3 H, J = 6.2 Hz, Me), 2.36 (s, 3 H, CH₃ *p*Tol), 2.82 (d, 1 H, J = 3.2 Hz, OH), 4.02 (quint, 1 H, J = 6.2 Hz, H-2), 4.31 (dd, 1 H, J = 6.9, 3.0 Hz, H-3), 5.49 (dd, 1 H, J = 9.9, 1.5 Hz, H-7_{cis}), 5.57 (dd, 1 H, J = 16.0, 1.5 Hz, H-7_{trans}), 6.67 (ddd, 1 H, J = 16.7, 11.3, 9.9 Hz, H-6), 7.06 (d, 1 H, J = 11.3 Hz, H-5), 7.24 (d, 2 H, J = 7.9 Hz, *p*Tol), 7.55 (d, 2 H, J = 8.5 Hz, *p*Tol). $^{13}\text{C NMR}$ (75 MHz) δ -4.7 (CH₃, TBDMS), -4.3 (CH₃, TBDMS), 18.0 (C-Si, TBDMS), 20.0 (Me), 21.4 (CH₃ *p*Tol), 25.8 (3 C, TBDMS), 71.9 (C-2), 73.2 (C-3), 124.9 (C-7), 125.6 (2 C), 129.7 (2 C), 130.5 (C-6), 133.3 (C-5), 141.3, 141.7, 145.3. IR (film): 3339, 2956, 2929, 2886, 2857, 1594, 1492, 1471, 1462, 1368, 1255, 1132, 1082, 1036, 1014, 975, 925, 881, 834, 810, 776, 755, 665 cm⁻¹. MS (ES): 381 [M+H]⁺ (100%).

Data for **2a**: R_f = 0.24 (30% EtOAc-hexane). $[\alpha]^{20}_D$ = +114.6 (c = 2.20). $^1\text{H NMR}$ (300 MHz)-COSY δ -0.03 (s, 3 H, TBDMS), -0.027 (s, 3 H, TBDMS), 0.82 (s, 9 H, TBDMS), 1.04 (d, 3 H, J = 6.0 Hz, Me), 2.37 (s, 3 H, CH₃ *p*Tol), 2.79 (d, 1 H, J = 4.1 Hz, OH), 3.69 (quint, 1 H, J = 6.0 Hz, H-2), 4.12 (dd, 1 H, J = 5.8, 4.1, H-3), 5.41 (dd, 1 H, J = 9.6, 1.5 Hz, H-7_{cis}), 5.49 (dd, 1 H, J = 16.5, 1.6 Hz, H-7_{trans}), 6.83 (d, 1 H, J = 11.3 Hz, H-5), 6.96 (ddd, 1 H, J = 16.5, 11.3, 9.6 Hz, H-6), 7.25 (d, 2 H, J = 8.5 Hz, *p*Tol), 7.54 (d, 2 H, J = 8.3 Hz, *p*Tol). $^{13}\text{C NMR}$ (75 MHz)-HSQC δ -4.75 (2 CH₃, TBDMS), 17.9 (C-Si, TBDMS), 18.9 (Me), 21.4 (CH₃ *p*Tol), 25.8 (3 C, TBDMS), 71.2 (C-2), 74.4 (C-3), 124.1 (C-7), 126.0 (2 C), 130.0 (2 C), 131.9 (C-6), 133.2 (C-5), 140.3, 142.0, 143.6. IR (film): 3339, 3087, 2956, 2929, 2886, 2857, 1594,

1493, 1471, 1463, 1402, 1368, 1304, 1255, 1179, 1133, 1082, 1036, 1014, 975, 925, 881, 834, 810, 776, 755, 703, 665, 624 cm⁻¹. **MS** (ES): 381 [M+H]⁺ (100%).

Synthesis of (+)-(5*S*,6*S*,*S*₅)-(3*E*)-6-(*t*-Butyldimethylsilyloxy)-4-(*p*-toluenesulfinyl)hept-3-en-1,2,5-triol, **3.**

A round-bottomed flask was charged with a solution of **2a** (180 mg, 0.47 mmol, 1.0 equiv) in a 9:1 mixture acetone:H₂O (10 mL/mmol), OsO₄ (0.29 mL, 0.023 mmol, 0.05 equiv, from a 2.5% solution of OsO₄ in *i*-PrOH), and Me₃N(O) (162 mg, 1.42 mmol, 3.0 equiv). This mixture was stirred at room temperature until complete consumption of the starting material (90 min). The solvent was then removed and the residue was filtered through a short pad of silica gel with EtOAc and 10% EtOH-EtOAc to eliminate the remaining osmium and evaporated. This crude was purified by column chromatography on silica gel (20-60% EtOAc-CH₂Cl₂) to render sulfoxide **3** (130 mg, 0.31 mmol, 66%) as a white solid and sulfone **4** (30 mg, 0.07 mmol, 15%) as a colorless oil.

Data for **3** (diastereomeric mixture): **mp**: 138-140 °C. **R_f** = 0.13 (60% EtOAc-CH₂Cl₂). **[α]²⁰_D** = +108.0 (*c* = 0.63). **¹H NMR (300 MHz)-COSY** δ 0.02 (s, 6 H, CH₃ TBDMS *maj*), 0.03 (s, 6 H, CH₃ TBDMS *min*), 0.85 (s, 9 H, *t*-Bu TBDMS *maj*), 0.86 (s, 9 H, *t*-Bu TBDMS *min*), 1.10 (d, 3 H, *J* = 6.1 Hz, CH₃), 1.11 (d, 3 H, *J* = 5.9 Hz, CH₃ *min*), 2.37 (s, 6 H, 2 CH₃ *pTol*), 3.59-3.87 (m, 6 H, H-6 + H-1), 4.13 (d, 2 H, *J* = 6.3 Hz, H-5), 4.73 (ap q, 2 H, *J* = 6.0 Hz, H-2), 6.42 (d, 1 H, *J* = 6.1 Hz, H-3 *maj*), 6.50 (d, 1 H, *J* = 5.9 Hz, H-3 *min*), 7.28 (d, 4 H, *J* = 8.3 Hz, *pTol*), 7.53 (d, 2 H, *J* = 8.3 Hz, *pTol*), 7.54 (d, 2 H, *J* = 8.1 Hz, *pTol*). **¹³C NMR (75 MHz)-HSQC** δ -4.8 (CH₃ TBDMS), -4.7 (CH₃ TBDMS), 18.0 (C *t*-Bu TBDMS), 19.7 (CH₃), 21.4 (CH₃ *pTol*), 25.8 (3 CH₃ *t*-Bu TBDMS), 65.7 (C-1), 69.3, 70.7 (C-2), 71.5 (C-6), 73.6 (C-5), 73.8, 126.4 (2 C *pTol*), 126.5, 130.1 (2 C *pTol*), 130.2, 131.5, 132.6 (C-3), 139.1, 139.3, 142.4, 142.7, 146.0, 147.2. **IR** (KBr): 3426, 2956, 2929, 2891, 2855, 1631, 1595, 1494, 1468, 1256, 1136, 1082, 1023, 835, 812, 775 cm⁻¹. **MS** (ES): 415 [M+H]⁺ (100%).

Data for **4** (diastereomeric mixture): $R_f = 0.23$ (30% EtOAc-CH₂Cl₂). $[\alpha]^{20}_D = +35.0$ ($c = 0.52$). **¹H NMR (300 MHz)** δ 0.07 (s, 3 H, CH₃ TBDMS *maj*), 0.08 (s, 3 H, CH₃ TBDMS *maj*), 0.09 (s, 6 H, 2 CH₃ TBDMS *min*), 0.85 (s, 18 H, 2 *t*-Bu TBDMS), 1.15 (d, 6 H, $J = 6.1$ Hz, 2 CH₃), 2.40 (s, 3 H, CH₃ *pTol maj*), 2.41 (s, 3 H, CH₃ *pTol min*), 3.59 (dd, 2 H, $J = 6.1, 4.8$ Hz, H-1 *maj*), 3.71 (dd, 2 H, $J = 10.9, 4.6$ Hz, H-1 *min*), 4.16 (ap q, 1 H, $J = 6.3$ Hz, H-6 *maj*), 4.28 (ap q, 1 H, $J = 4.9$ Hz, H-6 *min*), 4.43 (d, 1 H, $J = 4.9$ Hz, H-5 *min*), 4.55 (d, 1 H, $J = 5.1$ Hz, H-5 *maj*), 4.73 (dt, 1 H, $J = 6.6, 3.8$ Hz, H-2 *min*), 4.89 (ddd, 1 H, $J = 10.9, 6.3, 4.4$ Hz, H-2 *maj*), 6.97 (d, 1 H, $J = 7.0$ Hz, H-3 *maj*), 7.06 (d, 1 H, $J = 7.1$ Hz, H-3 *min*), 7.29 (d, 2 H, $J = 8.1$ Hz, *pTol*), 7.30 (d, 2 H, $J = 8.1$ Hz, *pTol*), 7.70 (d, 2 H, $J = 8.3$ Hz, *pTol*), 7.71 (d, 2 H, $J = 8.5$ Hz, *pTol*). **¹³C NMR (75 MHz)** δ -4.9 (CH₃ TBDMS), -4.7 (CH₃ TBDMS), 18.0 (CH₃), 21.6 (CH₃ *pTol*), 25.7 (3 CH₃ *t*-Bu TBDMS), 65.4 (C-1), 67.4, 69.9 (C-2), 70.3 (C-6), 73.6 (C-5), 74.1, 127.8 (2 C *pTol*), 128.0 (C-3), 129.9 (2 C *pTol*), 130.0, 137.1, 141.8, 142.3, 144.0. **IR (film)**: 3412, 2928, 2856, 1597, 1463, 1382, 1301, 1257, 1151, 1084, 977, 889, 837, 779, 757, 705, 667 cm⁻¹. **MS (ES)**: 431 [M+H]⁺ (100%).

General procedure for the oxidative cleavage of diols with NaIO₄.

A round-bottomed flask was charged with a solution of diol (1.0 equiv) in a 2:1 mixture MeOH:H₂O (20 mL/mmol). After chilling the mixture to 0 °C, NaIO₄ (3 equiv) was added and the reaction reached room temperature while stirring. Once the starting material disappeared (TLC) the mixture was evaporated, and partitioned with EtOAc and H₂O. The aqueous layer was extracted with EtOAc (3 times, 4 mL/mmol). The combined organic extracts were washed with a saturated solution of NaCl (4 mL/mmol), dried over MgSO₄ and concentrated under reduced pressure to give a crude product that was purified by column chromatography on silica gel using the appropriate mixture of eluents.

Synthesis of (+)-(1'S,5S,5S)-5-[1-(*t*-Butyldimethylsilyloxy)ethyl]-4-(*p*-toluenesulfinyl)-2,5-dihydrofuran-2-ol, 5.

From a solution of triol **3** (70 mg, 0.17 mmol, 1.0 equiv) in 4.5 mL of MeOH:H₂O (2:1) and NaIO₄ (108 mg, 0.51 mmol, 3.0 equiv), following the general procedure, lactol **5** (60 mg, 0.16 mmol, 94%, 50:50 mixture of anomers) was obtained as a colorless oil after chromatographic purification (40% EtOAc-CH₂Cl₂).

Data for **5**: R_f = 0.28 (40% EtOAc-CH₂Cl₂). $[\alpha]^{20}_D$ = +107.8 (c = 0.90). **¹H NMR (300 MHz)-COSY** δ 0.041 (s, 3 H, CH₃ TBDMS), 0.043 (s, 3 H, CH₃ TBDMS), 0.09 (s, 3 H, CH₃ TBDMS), 0.10 (s, 3 H, CH₃ TBDMS), 0.87 (s, 9 H, *t*-Bu TBDMS), 0.89 (s, 9 H, *t*-Bu TBDMS), 1.10 (d, 3 H, J = 6.3 Hz, CH₃), 1.16 (d, 3 H, J = 6.3 Hz, CH₃), 2.39 (s, 3 H, CH₃ *p*Tol), 3.25 (m, 1 H, OH), 3.40 (m, 1 H, OH), 3.76 (qd, 1 H, J = 6.3, 4.9 Hz, H-1'), 3.88 (qd, 1 H, J = 6.3, 4.9 Hz, H-1'), 4.08 (ddd, 1 H, J = 4.9, 1.7, 0.7 Hz, H-5), 4.32 (td, 1 H, J = 4.6, 1.9 Hz, H-5), 5.95 (d, 1 H, J = 9.0 Hz, H-2), 6.14 (ddd, 1 H, J = 8.5, 4.1, 1.2 Hz, H-2), 6.58 (dd, 1 H, J = 1.9, 1.2 Hz, H-3), 6.63 (t, 1 H, J = 1.5 Hz, H-3), 7.29 (d, 4 H, J = 8.3 Hz, *p*Tol), 7.55 (d, 2 H, J = 8.3 Hz, *p*Tol), 7.60 (d, 2 H, J = 8.3 Hz, *p*Tol). **¹³C NMR (50 MHz)-HSQC** δ -4.5, -4.29, -4.26, -3.9 (2 CH₃ TBDMS), 18.2 (C *t*-Bu TBDMS), 19.7 (CH₃), 21.5 (CH₃ *p*Tol), 26.0 (3 CH₃ *t*-Bu TBDMS), 70.9 (C-1'), 88.0, 88.4 (C-5), 91.2, 101.7, 102.1 (C-2), 125.9 (2 C *p*Tol), 130.4 (2 C *p*Tol), 130.8, 131.2 (C-3), 138.5, 138.9, 142.8, 142.9, 152.6, 153.3. **IR** (film): 3350, 2955, 2929, 2894, 2857, 1680, 1596, 1493, 1471, 1462, 1373, 1255, 1150, 1083, 972, 902, 832, 811, 778, 755, 665 cm⁻¹. **MS** (ES): 405 [M+Na]⁺, 383 [M+H]⁺ (100%).

Synthesis of (+)-(1'*S*,5*S*)-5-[1-(*t*-Butyldimethylsilyloxy)ethyl]-4-(*p*-toluenesulfonyl)-2,5-dihydrofuran-2-ol, **6**.

From a solution of triol **4** (56 mg, 0.13 mmol, 1.0 equiv) in 2.25 mL of MeOH:H₂O (2:1) and NaIO₄ (83 mg, 0.39 mmol, 3.0 equiv), following the general procedure, lactol **6** was obtained (40 mg, 0.10 mmol, 77%, 50:50 mixture of anomers) as a colorless oil after chromatographic purification (30% EtOAc-CH₂Cl₂).

Data for **6**: R_f = 0.33 (10% EtOAc-CH₂Cl₂). $[\alpha]^{20}_D$ = +9.7 (c = 0.64). **¹H NMR (300 MHz)** δ 0.06 (s, 6 H, 2 CH₃ TBDMS), 0.07 (s, 6 H, 2 CH₃ TBDMS), 0.86 (s, 9 H, *t*-Bu TBDMS), 0.87 (s, 9 H, *t*-Bu TBDMS),

0.96 (d, 3 H, $J = 6.1$ Hz, CH₃), 1.07 (d, 3 H, $J = 6.3$ Hz, CH₃), 2.45 (s, 6 H, 2 CH₃ *pTol*), 2.98 (d, 1 H, $J = 7.1$ Hz, OH), 3.29 (d, 1 H, $J = 7.8$ Hz, OH), 4.22 (m, 2 H, 2 H-1'), 4.85 (br s, 1 H, H-5), 5.03 (m, 1 H, H-5), 6.03 (d, 1 H, $J = 7.8$ Hz, H-2), 6.18 (ap t, 1 H, $J = 6.6$ Hz, H-2), 6.47 (br s, 1 H, H-3), 6.51 (d, 1 H, $J = 0.9$ Hz, H-3), 7.36 (d, 4 H, $J = 8.1$ Hz, *pTol*), 7.77 (d, 2 H, $J = 8.3$ Hz, *pTol*), 7.78 (d, 2 H, $J = 8.3$ Hz, *pTol*).

¹³C NMR (75 MHz) δ -4.9 (CH₃ TBDMS), -4.7 (2 CH₃ TBDMS), -4.5 (CH₃ TBDMS), 15.9 (C *t*-Bu TBDMS), 16.9 (C *t*-Bu TBDMS), 18.2 (2 CH₃), 21.7 (2 CH₃ *pTol*), 25.86 (3 CH₃ *t*-Bu TBDMS), 25.89 (3 CH₃ *t*-Bu, TBDMS), 68.5 (C-1'), 68.9 (C-1'), 88.2 (C-5), 88.6 (C-5), 100.7 (C-2), 101.8 (C-2), 128.3 (4 C *pTol*), 130.1 (2 C *pTol*), 130.2 (2 C *pTol*), 137.4 (C-3), 137.5 (C-3), 145.6, 146.8, 153.0. **IR** (film): 3518, 3447, 2929, 2857, 1627, 1596, 1462, 1382, 1324, 1257, 1155, 1102, 1017, 836, 813, 777, 706, 666 cm⁻¹.

MS (ES): 399 [M+H]⁺ (100%).

Synthesis of sulfinyl dehydropyranose **7**.

A round-bottomed flask was charged with a cold (0 °C) solution of lactol **5** (100 mg, 0.26 mmol, 1.0 equiv) in THF (4 mL) and TBAF (124 mg, 0.39 mmol, 1.5 equiv) from a 1 M solution in THF. The mixture reached room temperature and when the starting material disappeared (TLC) was quenched with a saturated solution of NH₄Cl (2 mL/mmol) and concentrated. The residue was filtered with EtOAc through a pad of silica gel and evaporated under vacuum. This crude mixture was redissolved in CH₂Cl₂ (5 mL/mmol) at room temperature and AcOH (30 μ L, 0.52 mmol, 2.0 equiv) was added. The mixture was stirred until disappearance of the starting material (TLC) and was neutralized with a saturated solution of NaHCO₃ (2 mL/mmol). Then, it was evaporated under vacuum and filtered with EtOAc through a pad of silica gel and concentrated again. The residue was purified by column chromatography on silica gel (10-30% EtOAc-CH₂Cl₂) rendering **7** (40 mg, 65%, 69:31 mixture of anomers) as a colorless oil.

Data for **7** (mixture of anomers): $R_f = 0.14$ (30% EtOAc-CH₂Cl₂). **¹H NMR (300 MHz)** δ 1.18 (d, 3 H, $J = 6.2$ Hz, Me *maj*), 1.20 (d, 3 H, $J = 6.1$ Hz, Me *min*), 1.80 (br s, 1 H, OH), 2.40 (s, 3 H, CH₃ *pTol min*), 2.41 (s, 3 H, CH₃ *pTol maj*), 3.70 (m, 1 H, H-6 *min*), 4.02 (m, 1 H, H-6 *maj*), 4.33 (br d, 1 H, $J = 5.6$ Hz,

OH), 4.60 (d, 1 H, $J = 2.9$ Hz, H-5 *min*), 4.80 (d, 1 H, $J = 3.2$ Hz, H-5 *maj*), 5.35 (dd, 1 H, $J = 6.3, 2.9$ Hz, H-2 *maj*), 5.52 (d, 1 H, $J = 6.4$ Hz, H-2 *min*), 6.48 (d, 1 H, $J = 1.0$ Hz, H-3 *maj*), 6.49 (d, 1 H, $J = 1.2$ Hz, H-3 *min*), 7.34 (m, 2 H, *pTol*), 7.54 (m, 2 H, *pTol*). ^{13}C NMR (75 MHz) δ 17.2 (CH₃ *maj*), 17.6 (CH₃ *min*), 21.4 (2 CH₃ *pTol*), 68.5 (C-6 *min*), 68.6 (C-6 *maj*), 69.7 (C-5 *maj*), 74.1 (C-5 *min*), 88.5 (C-2 *maj*), 91.1 (C-2 *min*), 124.7, 124.8 (2 C *pTol*), 126.2, 130.2 (2 C *pTol*), 130.4, 132.7, 142.2, 144.8. IR (film): 3350, 2977, 2927, 1595, 1493, 1449, 1381, 1305, 1011, 810, 755 cm⁻¹. MS (ES): 559 [2M+Na]⁺ (100%), 291 [M+Na]⁺, 269 [M+H]⁺.

General procedure for the synthesis of carbamates with benzyl isocyanate.

A round-bottomed flask was charged with a solution of lactol (1.0 equiv) in CH₂Cl₂ (5 mL/mmol). After cooling the mixture to 0 °C, 0.5 equiv of Et₃N was added, and after 15 min, benzyl isocyanate (1.5 equiv) was added dropwise. The reaction reached room temperature while stirring and once the starting material disappeared (TLC), the reaction was partitioned with EtOAc and H₂O. The aqueous layer was extracted with EtOAc (3 times, 4 mL/mmol). The combined organic extracts were washed with a saturated solution of NaCl (4 mL/mmol), dried over MgSO₄ and concentrated under reduced pressure to give a crude product that was purified by column chromatography on silica gel using the appropriate mixture of eluents.

Synthesis of (–)-(1'*S*,5*S*,5*S*)-5-[[1-(*t*-Butyldimethylsilyloxy)ethyl]-4-(*p*-toluenesulfinyl)-2,5-dihydrofuran-2-yl] *N*-benzyl carbamate, **8**.

From a solution of **5** (345 mg, 0.9 mmol, 1.0 equiv) in 4.5 mL of CH₂Cl₂, Et₃N (63 μ L, 0.45 mmol, 0.5 equiv) and benzyl isocyanate (0.17 mL, 1.35 mmol, 1.5 equiv) was obtained after chromatography (1-10% EtOAc-CH₂Cl₂), **8** (308 mg, 0.6 mmol, 67%) as an 83:17 mixture of anomers.

Data for **8** (major isomer): $R_f = 0.21$ (30% EtOAc-hexane). $[\alpha]^{20}_D = -53.8$ ($c = 0.29$). ^1H NMR (300 MHz) δ 0.06 (s, 3 H, CH₃ TBDMS), 0.08 (s, 3 H, CH₃ TBDMS), 0.88 (s, 9 H, *t*-Bu TBDMS), 1.12 (d, 3 H, $J = 6.3$ Hz, CH₃), 2.38 (s, 3 H, CH₃ *pTol*), 3.81 (qd, 1 H, $J = 6.3, 4.7$ Hz, H-1'), 4.31 (dt, 1 H, $J = 4.6,$

1.9 Hz, H-5), 4.30-4.40 (m, 2 H, CH₂Ph), 5.03 (br t, 1 H, NH), 6.60 (br s, 1 H, H-2), 6.96 (dd, 1 H, *J* = 4.2, 1.1 Hz, H-3), 7.25-7.31 (m, 7 H, *p*Tol + Ph), 7.60 (d, 2 H, *J* = 8.1 Hz, *p*Tol). **¹³C NMR (75 MHz)** δ -4.6 (CH₃ TBDMS), -4.2 (CH₃ TBDMS), 18.2 (CH₃), 20.2 (CH₃ *p*Tol), 26.0 (3 CH₃ *t*-Bu TBDMS), 45.0 (CH₂Ph), 70.6 (C-1'), 89.3 (C-5), 101.1 (C-2), 126.0 (2 C Ar), 127.6 (C-3), 127.6 (2 C Ar), 128.2 (C-4), 128.7 (2 C Ar), 130.4 (2 C Ar), 137.9, 138.7, 142.8, 154.8 (CO). **IR** (film): 3307, 2929, 2857, 1732, 1595, 1455, 1376, 1325, 1253, 1151, 1083, 1014, 962, 903, 835, 810, 777 cm⁻¹. **MS** (ES): 1053 [2M+Na]⁺.

Data for **8** (minor isomer): *R_f* = 0.16 (30% EtOAc-hexane). **¹H NMR (300 MHz)** δ 0.09 (s, 3 H, CH₃ TBDMS), 0.11 (s, 3 H, CH₃ TBDMS), 0.90 (s, 9 H, *t*-Bu TBDMS), 1.17 (d, 3 H, *J* = 6.1 Hz, CH₃), 2.39 (s, 3 H, CH₃ *p*Tol), 3.78 (q, 1 H, *J* = 6.1 Hz, H-1'), 4.05 (d, 1 H, *J* = 6.1 Hz, H-5), 4.37 (m, 2 H, CH₂Ph), 4.99 (br t, 1 H, NH), 6.55 (s, 1 H, H-2), 6.79 (s, 1 H, H-3), 7.21-7.32 (m, 7 H, *p*Tol + Ph), 7.57 (d, 2 H, *J* = 8.1 Hz, *p*Tol).

Synthesis of (1'*S*,5*S*)-5-[[1-(*t*-Butyldimethylsilyloxy)ethyl]-4-(*p*-toluenesulfonyl)-2,5-dihydrofuran-2-yl] *N*-benzyl carbamate, **9**.

From a solution of **6** (19 mg, 0.05 mmol, 1.0 equiv) in 0.25 mL of CH₂Cl₂, Et₃N (3 μL, 0.024 mmol, 0.5 equiv) and benzyl isocyanate (9 μL, 0.07 mmol, 1.5 equiv) was obtained, after chromatography (1-10% EtOAc-CH₂Cl₂), **9** (18 mg, 0.03 mmol, 72%) as an 80:20 mixture of anomers.

Data for **9** (major): *R_f* = 0.16 (30% EtOAc-hexane). **¹H NMR (300 MHz)** δ -0.06 (s, 6 H, CH₃ TBDMS), 0.75 (s, 9 H, CH₃ TBDMS), 0.84 (d, 3 H, *J* = 6.2 Hz, CH₃), 2.34 (s, 3 H, CH₃ *p*Tol), 4.12 (qd, 1 H, *J* = 6.2, 1.7 Hz, H-1'), 4.22-4.24 (m, 2 H, CH₂Ph), 4.90 (br t, 1 H, NH), 4.95 (m, 1 H, H-5), 6.39 (m, 1 H, H-2), 6.84 (dd, 1 H, *J* = 4.3, 1.1 Hz, H-3), 7.15-7.30 (m, 7 H, *p*Tol + Ph), 7.67 (d, 2 H, *J* = 8.3 Hz, *p*Tol). **¹³C NMR (75 MHz)** δ -4.9 (CH₃ TBDMS), -4.7 (CH₃ TBDMS), 15.9 (C *t*-Bu TBDMS), 18.2 (CH₃), 21.7 (CH₃ *p*Tol), 25.8 (3 CH₃ *t*-Bu TBDMS), 45.0 (CH₂Ph), 68.6 (C-1'), 89.4 (C-5), 101.2 (C-2), 127.5 (2 C Ar), 127.6 (C-3), 128.3 (2 C Ar), 128.7 (2 C Ar), 130.1 (2 C Ar), 135.5 (C-4), 137.8, 145.7, 148.1, 154.3

(CO). **IR** (film): 3380, 3031, 2955, 2929, 2857, 1732, 1596, 1520, 1455, 1381, 1324, 1304, 1253, 1184, 1156, 1100, 1005, 982, 910, 837, 813, 777, 755, 703, 666, 591 cm^{-1} . **MS** (ES): 532 $[\text{M}+\text{H}]^+$ (100%).

General procedure for the intramolecular Michael addition with K_2CO_3 .

A round-bottomed flask was charged with a solution of carbamate (1.0 equiv) in a 50:50 mixture of $\text{MeOH}:\text{CH}_2\text{Cl}_2$ (10 mL/mmol) and 10 equiv of solid K_2CO_3 was added portionwise. The reaction mixture was stirred at room temperature and once the starting material disappeared (TLC), the reaction was partitioned with EtOAc (10 mL/mmol) and H_2O (10 mL/mmol). The aqueous layer was extracted with EtOAc (3 times, 4 mL/mmol). The combined organic extracts were washed with a saturated solution of NaCl (4 mL/mmol), dried over MgSO_4 and concentrated under reduced pressure to give a crude product that was purified by column chromatography on silica gel using the appropriate mixture of eluents.

Synthesis of (+)-(1'S,3aS,5S,6aR,6R,S_S)-1-Benzyl-5-[1-(*t*-butyldimethylsilyloxy)ethyl]-6-(*p*-toluenesulfinyl)tetrahydrofuro[3,2-*d*]oxazol-2-one, 10, and (+)-(1'S,3aR,5S,6aS,6R,S_S)-1-Benzyl-5-[1'-(*t*-butyldimethylsilyloxy)ethyl]-6-(*p*-toluenesulfinyl)tetrahydrofuro[3,2-*d*]oxazol-2-one, 10'.

From a solution of an 83:17 anomeric mixture of **8** (234 mg, 0.45 mmol, 1.0 equiv) in 4.6 mL of $\text{CH}_2\text{Cl}_2:\text{MeOH}$ and K_2CO_3 (628 mg, 4.5 mmol, 10.0 equiv), was obtained, after chromatography (10-40% EtOAc -hexane), (3aS,6aR)-**10** (170 mg, 56%) and (3aR,6aS)-**10'** (20 mg, 9%) as colorless oils.

Data for (3aS,6aR)-**10**: $R_f = 0.17$ (40% EtOAc -hexane). $[\alpha]^{20}_{\text{D}} = +145.5$ ($c = 0.89$). **^1H NMR (300 MHz)-COSY** δ -0.13 (s, 3 H, CH_3 TBDMS), -0.12 (s, 3 H, CH_3 TBDMS), 0.08 (d, 3 H, $J = 6.6$ Hz, CH_3), 0.63 (s, 9 H, *t*-Bu TBDMS), 2.38 (s, 3 H, CH_3 *p*Tol), 3.05 (dd, 1 H, $J = 8.5, 1.9$ Hz, H-6), 3.77 (qd, 1 H, $J = 6.6, 1.7$ Hz, H-1'), 4.31 (d, 1 H, $J = 14.9$ Hz, CH_2Ph), 4.32 (dd, 1 H, $J = 6.4, 1.9$ Hz, H-6a), 4.55 (s, 1 H, H-5), 5.16 (d, 1 H, $J = 14.9$ Hz, CH_2Ph), 5.90 (d, 1 H, $J = 6.4$ Hz, H-3a), 7.29-7.40 (m, 7 H, *p*Tol + Ph), 7.43 (d, 2 H, $J = 8.1$ Hz, *p*Tol). **NOE-1D**: H-3a / H-6a (4.5%); H-6 / H-6a (7.5%); H-5 / H-1' (4.6%). **^{13}C NMR (75 MHz)-HSQC** δ -5.0 (CH_3 TBDMS), -4.7 (CH_3 TBDMS), 17.5 (C *t*-Bu TBDMS), 17.8 (CH_3), 21.4

(CH₃ *p*Tol), 25.6 (3 CH₃ *t*-Bu TBDMS), 48.9 (CH₂Ph), 60.8 (C-6a), 65.4 (C-6), 70.3 (C-1'), 83.6 (C-5), 103.2 (C-3a), 124.3 (2 C Ar), 128.5, 128.6 (2 C Ar), 129.1 (2 C Ar), 130.3 (2 C Ar), 135.1, 138.6, 141.8, 156.2 (CO). **IR** (film): 3028, 2949, 2928, 2847, 1748, 1631, 1414, 1257, 1206, 1085, 1041, 811, 775, 702 cm⁻¹. **MS** (ES): 516 [M+H]⁺ (100%).

Data for (3a*R*,6a*S*)-**10'**: *R*_f = 0.25 (30% EtOAc-hexane). [α]_D²⁰ = +63.0 (*c* = 1.20). **¹H NMR (300 MHz)-COSY** δ 0.06 (s, 3 H, CH₃ TBDMS), 0.07 (s, 3 H, CH₃ TBDMS), 0.90 (s, 9 H, *t*-Bu TBDMS), 1.18 (d, 3 H, *J* = 6.1 Hz, CH₃), 2.38 (s, 3 H, CH₃ *p*Tol), 3.57 (dq, 1 H, *J* = 8.9, 6.1 Hz, H-1'), 3.71 (br s, 1 H, H-6), 3.81 (d, 1 H, *J* = 14.6 Hz, CH₂Ph), 3.97 (dd, 1 H, *J* = 9.0, 1.9 Hz, H-5), 4.32 (d, 1 H, *J* = 6.1 Hz, H-6a), 4.83 (d, 1 H, *J* = 14.8 Hz, CH₂Ph), 5.23 (d, 1 H, *J* = 6.1 Hz, H-3a), 7.25-7.36 (m, 7 H, *p*Tol + Ph), 7.41 (d, 2 H, *J* = 8.3 Hz, *p*Tol). **NOE-1D**: H-3a / H-6a (6.0%); H-6 / H-1' (4.0%); H-5 / Me (9.1%); H-1' / Me (5.2%); H-1' / H-5 (2.1%). **¹³C NMR (75 MHz)-HSQC** δ -4.3 (CH₃ TBDMS), -3.5 (CH₃ TBDMS), 17.5 (C *t*-Bu TBDMS), 21.5 (CH₃), 21.9 (CH₃ *p*Tol), 26.2 (3 CH₃ *t*-Bu TBDMS), 46.9 (CH₂Ph), 59.4 (C-6a), 66.5 (C-6), 70.4 (C-1'), 85.0 (C-5), 102.5 (C-3a), 125.3 (2 C Ar), 128.8, 129.4 (2 C Ar), 129.6 (2 C Ar), 130.7 (2 C Ar), 135.1, 136.5, 143.3, 155.7 (CO). **IR** (film): 2929, 2855, 1766, 1418, 1237, 1103, 1051, 1006, 835, 777, 752, 702 cm⁻¹. **MS** (ES): 516 [M+H]⁺ (100%).

Synthesis of (+)-(1'*S*,3a*S*,5*S*,6a*R*,6*R*)-1-Benzyl-5-[1-(*t*-butyldimethylsilyloxy)ethyl]-6-(*p*-toluenesulfonyl)tetrahydrofuro[3,2-*d*]oxazol-2-one, **11.**

From a solution of **9** (29 mg, 0.06 mmol, 1.0 equiv) in 0.6 mL of CH₂Cl₂:MeOH and K₂CO₃ (76 mg, 0.6 mmol, 10.0 equiv), was obtained, after chromatography (15-40% EtOAc-hexane), **11** (25 mg, 80%) as a colorless oil.

Data for **11**: *R*_f = 0.25 (30% EtOAc-hexane). [α]_D²⁰ = +39.8 (*c* = 1.19). **¹H NMR (300 MHz)** δ -0.15 (s, 3 H, CH₃ TBDMS), -0.09 (s, 3 H, CH₃ TBDMS), 0.60 (s, 9 H, *t*-Bu TBDMS), 0.63 (d, 3 H, *J* = 6.6 Hz, CH₃), 2.44 (s, 3 H, CH₃ *p*Tol), 3.77 (m, 2 H, H-5, H-1'), 4.26 (dd, 1 H, *J* = 8.3, 6.3 Hz, H-6a), 4.42 (d, 1 H, *J* = 14.9 Hz, CH₂Ph), 4.59 (t, 1 H, *J* = 2.4 Hz, H-6), 5.03 (d, 1 H, *J* = 15.1 Hz, CH₂Ph), 5.75 (d, 1 H, *J* =

6.3 Hz, H-3a), 7.26-7.34 (m, 5 H, Ph), 7.38 (d, 2 H, $J = 8.1$ Hz, *p*Tol), 7.82 (d, 2 H, $J = 8.5$ Hz, *p*Tol). ^{13}C NMR (75 MHz) δ -5.1 (CH₃ TBDMS), -4.6 (CH₃ TBDMS), 14.5 (C *t*-Bu TBDMS), 18.6 (CH₃), 21.7 (CH₃ *p*Tol), 25.5 (3 CH₃ *t*-Bu TBDMS), 48.4 (CH₂Ph), 60.1 (C-6a), 65.2 (C-6), 70.2 (C-1'), 87.7 (C-5), 102.8 (C-3a), 128.3 (2 C Ar), 128.6 (2 C Ar), 129.1 (3 C), 130.2 (2 C Ar), 135.0, 135.5, 145.8, 156.3 (CO). IR (film): 2956, 2927, 2855, 1758, 1630, 1319, 1147, 839, 604 cm⁻¹. MS (ES): 532 [M+H]⁺ (100%).

Oxidation of sulfoxide **10** with MMPP to sulfone **11**.

To a cold (0 °C) solution of sulfoxide (3a*S*,6a*R*)-**10** (19 mg, 0.037 mmol, 1.0 equiv) in MeOH (0.4 mL, 10 mL/mmol) was added MMPP (35 mg, 0.06 mmol, 1.5 equiv). The reaction mixture was stirred and warmed to room temperature and once the starting material disappeared (TLC), it was quenched with a saturated solution of NaHCO₃ (4 mL/mmol) and then MeOH was evaporated under vacuum. The reaction residue was partitioned with EtOAc (10 mL/mmol) and H₂O (10 mL/mmol). The aqueous layer was extracted with EtOAc (3 times, 4 mL/mmol). The combined organic extracts were washed with a saturated solution of NaCl (1 mL/mmol), dried over MgSO₄ and concentrated under reduced pressure to give a crude product that was purified by column chromatography on silica gel (2-10% EtOAc-CH₂Cl₂) yielding sulfone **11** (18 mg, 92%) as a colorless oil and with identical data to that found before.

Synthesis of (–)-(2*S*,3*S*,4*R*,5*R*)-5-Benzylamino-2-methyl-6-methoxy-4-(*p*-toluenesulfonyl)tetrahydropyran-3-ol, **12**.

A Kimble vessel was charged with sulfone **11** (14 mg, 0.034 mmol, 1.0 equiv), 0.2 mL of MeOH, a 6 N solution of HCl (0.27 mL, 1.62 mmol) and heated at 80-90 °C for 3 days until complete disappearance of the starting material (TLC). The mixture was concentrated under vacuum and then it was redissolved in a 9:1 mixture of CHCl₃:H₂O (15 mL/mmol), K₂CO₃ (15 mg, 0.11 mmol, 3.0 equiv) was added and it was stirred for 2 days. The organic layer was separated and evaporated under vacuum and the crude residue was

purified by column chromatography on silica gel (10-50% EtOAc-CH₂Cl₂) rendering **12** (major, 6 mg, 43%) and **12'** (minor, 3 mg, 20%) as colorless liquids.

Data for **12**: $R_f = 0.18$ (30% EtOAc-hexane). $[\alpha]^{20}_D = -8.2$ ($c = 0.49$). **¹H NMR (300 MHz)** δ 1.23 (d, 3 H, $J = 7.3$ Hz, CH₃), 2.42 (s, 3 H, CH₃ *p*Tol), 3.28 (br s, 1 H, H-3), 3.35 (s, 3 H, OCH₃), 3.53 (t, 1 H, $J = 2.5$ Hz, H-3), 3.64 (d, 1 H, $J = 13.2$ Hz, CH₂Ph), 3.90 (d, 1 H, $J = 13.4$ Hz, CH₂Ph), 3.94 (br s, 1 H, H-4), 4.15 (qd, 1 H, $J = 7.3, 1.7$ Hz, H-2), 4.84 (d, 1 H, $J = 1.9$ Hz, H-6), 7.27-7.34 (m, 7 H, *p*Tol + Ph), 7.73 (d, 2 H, $J = 8.3$ Hz, *p*Tol). **NOE-1D**: H-4 / H-3 (3.4%); H-3 / Me (5.5%); H-3 / H-4 (5.5%); H-3 / H-5 (4.6%). **¹³C NMR (100 MHz)** δ 19.5 (CH₃), 21.7 (CH₃ *p*Tol), 51.4 (CH₂Ph), 55.0 (C-5), 55.7 (OCH₃), 58.5 (C-3), 68.7 (C-4), 76.7 (C-2), 98.9 (C-6), 127.4, 128.2 (2 C Ar), 128.60 (2 C Ar), 128.63 (2 C Ar), 129.9 (2 C Ar), 135.5, 138.7, 145.1. **IR** (film): 3400, 2926, 1596, 1454, 1261, 1087, 815, 759, 651 cm⁻¹. **MS** (ES): 406 [M+H]⁺ (100%).

Partial data for **12'**: $R_f = 0.11$ (40% EtOAc-hexane). **¹H NMR (300 MHz)** δ 1.08 (d, 3 H, $J = 6.6$ Hz, CH₃), 2.44 (s, 3 H, CH₃ *p*Tol), 3.11 (d, 1 H, $J = 3.1$ Hz, H-5), 3.33 (s, 3 H, OCH₃), 3.69 (d, 1 H, $J = 13.3$ Hz, CH₂Ph), 3.72 (d, 1 H, $J = 13.3$ Hz, CH₂Ph), 3.81 (m, 1 H, H-2), 3.96 (dd, 1 H, $J = 7.2, 5.2$ Hz, H-3), 4.47 (t, 1 H, $J = 5.2$ Hz, H-4), 4.78 (d, 1 H, $J = 2.4$ Hz, H-6), 7.17-7.33 (m, 7 H, *p*Tol + Ph), 7.81 (d, 2 H, $J = 8.3$ Hz, *p*Tol).

Synthesis of (+)-(1'S,3aS,5S,6aS,6R)-1-Benzyl-5-[1'-(*t*-butyldimethylsilyloxy)ethyl]-6-hydroxytetrahydrofuro[3,2-*d*]oxazol-2-one, **15 and vinyl sulfide **13**.**

Pummerer reaction: A Kimble vessel was charged with sulfoxide (3a*S*,6a*R*)-**10** (25 mg, 0.048 mmol, 1.0 equiv) in 0.5 mL of C₆H₆ and TFAA, freshly distilled from P₂O₅, (33.4 μ L, 0.24 mmol, 5.0 equiv) and heated at 40 °C; after 10 h more TFAA (16.7 μ L, 0.12 mmol, 2.5 equiv) was added to complete the disappearance of the starting material (18 h). The mixture was neutralized with a 5% solution of NaHCO₃ (10 mL/mmol) and was diluted with EtOAc (5 mL/mmol). The aqueous layer was extracted with EtOAc (3 times, 4 mL/mmol). The combined organic extracts were washed with a saturated solution of NaCl, dried

over MgSO₄ and concentrated. Chromatographic purification gave a 50:50 inseparable mixture of **14** and **13** (20 mg) that was used for the subsequent reduction. **Reduction reaction:** To a cold (−78 °C) suspension of NaBH₄ (6 mg, 0.15 mmol, 6.25 equiv) in 0.25 mL of EtOH, the above mixture in 0.25 mL of EtOH was added. After complete disappearance of **14** (TLC) the reaction was quenched with saturated solution of NaCl (2 mL/mmol) and H₂O (2 mL/mmol). The mixture was stirred and warmed to room temperature and then it was concentrated under vacuum, filtered through a short pad of silica gel and evaporated again. After chromatographic purification on silica gel (10-30% EtOAc-hexane), pure alcohol **15** (8.4 mg, 42% from **10**) and pure vinyl sulfide **13** (7 mg) were isolated as colorless oils.

Partial data for **14**, (1'S,3aS,5S,6aR)-1-Benzyl-5-[1'-(*t*-butyldimethylsilyloxy)ethyl]-dihydrofuro[3,2-*d*]oxazol-2,6-dione, (from the mixture): *R_f* = 0.28 (20% EtOAc-hexane). ¹H NMR (300 MHz) δ 0.01 (s, 3 H, CH₃ TBDMS), 0.02 (s, 3 H, CH₃ TBDMS), 0.88 (s, 9 H, *t*-Bu TBDMS), 1.24 (d, 3 H, *J* = 6.6 Hz, CH₃), 3.65 (d, 1 H, *J* = 6.1 Hz, H-6a), 4.09-4.14 (m, 2 H, H-1', H-5), 4.24 (d, 1 H, *J* = 14.9 Hz, CH₂Ph), 4.88 (d, 1 H, *J* = 14.9 Hz, CH₂Ph), 6.13 (d, 1 H, *J* = 6.1 Hz, H-3a), 7.06 (d, 2 H, *J* = 6.8 Hz, Ph), 7.33-7.36 (m, 3 H, Ph). ¹³C NMR (75 MHz) δ −4.8 (CH₃ TBDMS), −4.7 (CH₃ TBDMS), 17.7 (C *t*-Bu TBDMS), 18.2 (CH₃), 25.6 (3 CH₃ *t*-Bu, TBDMS), 45.7 (CH₂Ph), 57.7 (C-6a), 70.2 (C-1'), 82.7 (C-6), 98.8 (C-3a), 128.4 (C Ph), 128.9 (2 C Ph), 129.0 (2 C Ph), 130.2 (C Ph), 155.4 (CO, oxazolidinone), 205.8 (CO, ketone). MS (ES): 424 [M+MeOH]⁺, 414 [M+Na]⁺, 392 [M+H]⁺.

Data for **13**: *R_f* = 0.20 (20% EtOAc-hexane). [*α*]_D²⁰ = +33.9 (*c* = 0.33). ¹H NMR (300 MHz)-COSY δ 0.07 (s, 3 H, CH₃ TBDMS), 0.08 (s, 3 H, CH₃ TBDMS), 0.88 (s, 9 H, *t*-Bu TBDMS), 1.34 (d, 3 H, *J* = 6.6 Hz, CH₃), 2.31 (s, 3 H, CH₃ *p*Tol), 4.26 (d, 1 H, *J* = 14.9 Hz, CH₂Ph), 4.49 (d, 1 H, *J* = 7.3 Hz, H-6a), 4.81 (d, 1 H, *J* = 14.9 Hz, CH₂Ph), 4.94 (q, 1 H, *J* = 6.6 Hz, H-1'), 6.18 (d, 1 H, *J* = 7.1 Hz, H-3a), 7.02-7.09 (m, 5 H, Ph), 7.17-7.20 (m, 4 H, *p*Tol). ¹³C NMR (75 MHz)-HSQC δ −4.8 (CH₃ TBDMS), −4.6 (CH₃ TBDMS), 18.1 (C *t*-Bu TBDMS), 20.9 (CH₃ *p*Tol), 21.9 (CH₃), 25.7 (3 CH₃ *t*-Bu TBDMS), 46.7 (CH₂Ph), 61.6 (C-6a), 62.3 (C-1'), 99.9 (C-6), 100.5 (C-3a), 127.6 (2 C Ar), 128.0 (C Ph), 128.5 (2 C Ar), 128.7 (2 C Ar), 130.2 (2 C Ar), 130.9, 135.3, 136.7, 155.5 (C-5), 167.5 (CO). IR (film): 3028, 2928, 2856, 1770,

1638, 1492, 1413, 1339, 1257, 1222, 1101, 1007, 972, 833, 807, 778, 704 cm^{-1} . **MS** (ES): 498 $[\text{M}+\text{H}]^+$ (100%).

Data for **15**: $R_f = 0.21$ (30% EtOAc-hexane). $[\alpha]^{20}_{\text{D}} = +15.5$ ($c = 0.93$). **^1H NMR (300 MHz)-COSY** δ 0.07 (s, 3 H, CH_3 TBDMS), 0.09 (s, 3 H, CH_3 TBDMS), 0.87 (s, 9 H, *t*-Bu TBDMS), 1.26 (d, 3 H, $J = 6.3$ Hz, CH_3), 2.56 (br s, 1 H, OH), 3.69 (dd, 1 H, $J = 8.1, 6.6$ Hz, H-5), 3.87 (quint, 1 H, $J = 6.3$ Hz, H-1'), 3.97 (t, 1 H, $J = 5.9$ Hz, H-6a), 4.08 (ddd, 1 H, $J = 10.9, 6.1, 2.9$ Hz, H-6), 4.45 (d, 1 H, $J = 14.9$ Hz, CH_2Ph), 4.95 (d, 1 H, $J = 14.9$ Hz, CH_2Ph), 5.75 (d, 1 H, $J = 5.9$ Hz, H-3a), 7.28-7.36 (m, 5 H, Ph). **NOE-1D**: H-3a / H-6a (4.2%); H-6a / H-6 (2.3%); H-1' / H-6 (3.6%). **^{13}C NMR (100 MHz)-HSQC** δ -4.8 (CH_3 TBDMS), -4.2 (CH_3 TBDMS), 17.9 (C *t*-Bu TBDMS), 21.6 (CH_3), 25.7 (3 CH_3 *t*-Bu TBDMS), 47.6 (CH_2Ph), 58.8 (C-6a), 70.7 (C-1'), 76.0 (C-5), 83.0 (C-6), 99.7 (C-3a), 128.0, 128.8, 128.8, 135.7, 157.8 (CO). **IR** (film): 3400, 2926, 2854, 1738, 1456, 1377, 1258, 1115, 976, 829, 779, 705 cm^{-1} . **MS** (ES): 394 $[\text{M}+\text{H}]^+$ (100%).

Synthesis of 1-(3-(*p*-toluenesulfinyl)furan-2-yl)ethanol, **16a**.

To a solution of lactol **5** (9 mg, 0.02 mmol, 1.0 equiv) in CHCl_3 (1 mL) at rt was added trimethylsilyl iodide (1.2 equiv, 0.029 mmol, 4 μL) and the mixture was stirred 4 h until complete disappearance of the starting lactol. Then, MeOH (1 mL) was added and the mixture was stirred 1 h more. Removal of the solvent under vacuum and chromatography on silica gel of the crude residue (20-50% EtOAc- CHCl_3) yielded **16a** (2 mg, 33%) as a yellow oil.

Data for **16a**: $R_f = 0.3$ (30% EtOAc- CHCl_3). **^1H NMR (300 MHz)** δ 1.57 (d, 3 H, $J = 6.6$ Hz, CH_3), 2.37 (s, 3 H, CH_3 *p*Tol), 3.86 (brs, 1 H, OH); 5.07 (m, 1 H, H-1), 6.23 (d, 1 H, $J = 1.9$ Hz, H-4), 7.23 (m, 3 H, $J = 7.8$ Hz, 2 H_m *p*Tol, H-5), 7.54 (d, 2 H, $J = 8.3$ Hz, 2 H_o *p*Tol). **^{13}C NMR (75 MHz)** δ 21.4 (CH_3 *p*Tol), 21.6 (CH_3), 63.3 (C-1), 108.5 (C-4), 124.9 (2 C_o *p*Tol), 125.3 (C-3), 130.1 (2 C_m *p*Tol), 142.2 (C-5, C_p *p*Tol, C_{ipso} *p*Tol), 159.9 (C-2).

General procedure for the ozonolysis of α -hydroxy sulfinyl dienes. Synthesis of sulfinyl furans.

Through a cold ($-78\text{ }^{\circ}\text{C}$) solution of 1.0 equiv (0.24-0.68 mmol) of the α -hydroxy sulfinyl diene **2** in CH_2Cl_2 (20 mL/mmol) was bubbled O_2 for 5-10 min, followed by a 6% mixture O_3/O_2 for 5-10 min. An excess of SMe_2 (2 mL) was then added dropwise and the mixture was stirred at room temperature for 1-2 hours. The solvent was removed under reduced pressure and the crude product was purified by column chromatography on silica gel using the appropriate mixture of eluents.

Synthesis of (–)-(S)-2-Ethyl-3-(*p*-toluenesulfinyl)furan, **16b**.

From α -hydroxy sulfinyl diene **2b** (99 mg, 0.40 mmol) in 8 mL of CH_2Cl_2 bubbling O_3/O_2 (5 min) and with SMe_2 , according to the general procedure, sulfinyl furan **16b** (65 mg, 70%) was obtained as a colorless oil after chromatography (0-30% EtOAc-hexane). Small amounts of 2-ethyl-3-(*p*-toluenesulfonyl)furan **17b** were also isolated during the optimization of reaction conditions (see table 1).

Data for **16b**: $R_f = 0.20$ (50% EtOAc-hexane). $[\alpha]^{20}_{\text{D}} = -93.8$ ($c = 5.1$). $^1\text{H NMR}$ (300 MHz) δ 1.28 (t, 3 H, $J = 7.6$ Hz, CH_3 Et), 2.35 (s, 3 H, CH_3 *p*Tol), 2.91 (q, 2 H, $J = 7.6$ Hz, CH_2 Et), 6.17 (d, 1 H, $J = 2.0$ Hz, H-4), 7.21 (d, 1 H, $J = 2.0$ Hz, H-5), 7.25 (d, 2 H, $J = 8.1$ Hz, 2 H_m *p*Tol), 7.44 (d, 2 H, $J = 8.1$ Hz, 2 H_o *p*Tol). $^{13}\text{C NMR}$ (75 MHz) δ 12.8 (CH_3 Et), 20.1 (CH_3 *p*Tol), 21.2 (CH_2 Et), 107.4 (C-4), 124.0 (C-3), 124.2 (2 C_o *p*Tol), 129.7 (2 C_m *p*Tol), 140.8 (C_{ipso} *p*Tol), 141.0 (C_p *p*Tol), 142.1 (C-5), 160.4 (C-2). IR (film): 3112, 3050, 2977, 2919, 2875, 1579, 1516, 1493, 1455, 1380, 1200, 1122, 1084, 1049, 993, 888, 811, 739, 705 cm^{-1} . MS (ES): 491 $[\text{2M}+\text{Na}]^+$, 469 $[\text{2M}+\text{H}]^+$, 257 $[\text{M}+\text{Na}]^+$, 235 $[\text{M}+\text{H}]^+$ (100%).

Partial data for **17b**: $R_f = 0.30$ (50% EtOAc-hexane). $^1\text{H NMR}$ (300 MHz) δ 1.20 (t, 3 H, $J = 7.6$ Hz, CH_3 Et), 2.40 (s, 3 H, CH_3 *p*Tol), 2.98 (q, 2 H, $J = 7.6$ Hz, CH_2 Et), 6.54 (d, 1 H, $J = 2.0$ Hz, H-4), 7.24 (d, 1 H, $J = 2.0$ Hz, H-5), 7.29 (d, 2 H, $J = 7.8$ Hz, 2 H_m *p*Tol), 7.78 (d, 2 H, $J = 8.3$ Hz, 2 H_o *p*Tol).

Synthesis of (–)-(S)-2-*i*-Propyl-3-(*p*-toluenesulfinyl)furan, **16c**.

From α -hydroxy sulfinyl diene **2c** (179 mg, 0.68 mmol) in 14 mL of CH₂Cl₂ bubbling O₃/O₂ (5 min) and with SMe₂, according to the general procedure, sulfinyl furan **16c** (122 mg, 73%) was obtained as a colorless oil after chromatography (10-30% EtOAc-hexane).

Data for **16c**: R_f = 0.31 (30% EtOAc-hexane). $[\alpha]^{20}_D$ = -102.9 (c = 9.10). **¹H NMR (300 MHz)-COSY** δ 1.32 (d, 3 H, J = 6.8 Hz, CH₃ *i*-Pr), 1.34 (d, 3 H, J = 6.8 Hz, CH₃ *i*-Pr), 2.37 (s, 3 H, CH₃ *p*-Tol), 3.46 (hept, 1 H, J = 7.1 Hz, CH *i*-Pr), 6.18 (d, 1 H, J = 2.0 Hz, H-4), 7.22 (d, 1 H, J = 2.2 Hz, H-5), 7.27 (d, 2 H, J = 7.8 Hz, 2 H_{*m*} *p*Tol), 7.46 (d, 2 H, J = 8.3 Hz, 2 H_{*o*} *p*Tol). **¹³C NMR (75 MHz-HSQC** δ 21.2 (CH₃ *i*-Pr), 21.3 (CH₃ *i*-Pr), 21.8 (CH₃ *p*Tol), 27.1 (CH *i*-Pr), 107.3 (C-4), 123.1 (C-3), 124.3 (2 C_{*o*} *p*Tol), 129.8 (2 C_{*m*} *p*Tol), 140.8 (C_{*ipso*} *p*Tol), 141.2 (C_{*p*} *p*Tol), 142.0 (C-5), 163.7 (C-2). **IR** (film): 3108, 2969, 1574, 1519, 1462, 1317, 1246, 1210, 1116, 1083, 1038, 810 cm⁻¹. **MS** (ES): 519 [2M+Na]⁺, 497 [2M+H]⁺, 271 [M+Na]⁺, 249 [M+H]⁺ (100%).

Synthesis of (–)-(S)-2-*t*-Butyl-3-(*p*-toluenesulfinyl)furan, **16d**.

From α -hydroxy sulfinyl diene **2d** (151 mg, 0.54 mmol) in 10 mL of CH₂Cl₂ bubbling O₃/O₂ (30 min) and with SMe₂, according to the general procedure, sulfinyl furan **16d** (103 mg, 72%) was obtained as a colorless oil after chromatography (10-50% EtOAc-hexane). During the purification 23 mg (15%) of the oxidation product **17d** was also isolated as a colorless oil.

Data for **16d**: R_f = 0.17 (50% EtOAc-hexane). $[\alpha]^{20}_D$ = -131.4 (c = 2.7). **¹H NMR (300 MHz)** δ 1.48 (s, 9 H, 3 CH₃ *t*-Bu), 2.37 (s, 3 H, CH₃ *p*Tol), 6.24 (d, 1 H, J = 2.0 Hz, H-4), 7.19 (d, 1 H, J = 2.0 Hz, H-5), 7.27 (d, 2 H, J = 7.8 Hz, 2 H_{*m*} *p*Tol), 7.47 (d, 2 H, J = 8.3 Hz, 2 H_{*o*} *p*Tol). **¹³C NMR (75 MHz)** δ 21.3 (CH₃ *p*Tol), 30.1 (3 CH₃ *t*-Bu), 34.8 (C *t*-Bu), 108.4 (C-4), 123.6 (C-3), 124.5 (2 C_{*o*} *p*Tol), 129.8 (2 C_{*m*} *p*Tol), 140.8 (C_{*ipso*} *p*Tol), 140.9 (C_{*p*} *p*Tol), 141.5 (C-5), 165.0 (C-2). **IR** (film): 3137, 3116, 2969, 2881, 2856, 1596, 1557, 1514, 1493, 1458, 1397, 1363, 1302, 1265, 1199, 1151, 1084, 1049, 990, 888, 810, 747, 708 cm⁻¹. **MS** (ES): 547 [2M+Na]⁺, 525 [2M+H]⁺ (100%), 285 [M+Na]⁺, 263 [M+H]⁺.

Partial data for **17d**: $R_f = 0.26$ (50% EtOAc-hexane). $^1\text{H NMR}$ (300 MHz) δ 1.38 (s, 9 H, 3 CH₃ *t*-Bu), 2.39 (s, 3 H, CH₃ *p*Tol), 6.61 (d, 1 H, $J = 2.0$ Hz, H-4), 7.21 (d, 1 H, $J = 2.0$ Hz, H-5), 7.27 (d, 2 H, $J = 7.8$ Hz, 2 H_{*m*} *p*Tol), 7.76 (d, 2 H, $J = 8.3$ Hz, 2 H_{*o*} *p*Tol). $^{13}\text{C NMR}$ (75 MHz) δ 20.5 (CH₃ *p*-Tol), 28.1 (3 CH₃ *t*-Bu), 34.0 (C *t*-Bu), 112.1 (C-4), 121.1 (C-3), 126.1 (2 C_{*o*} *p*Tol), 129.6 (2 C_{*m*} *p*Tol), 138.0 (C-5), 139.1 (C_{*ipso*} *p*Tol), 142.8 (C_{*p*} *p*Tol), 164.2 (C-2).

Synthesis of (±)-2-*p*-Fluorophenyl-3-(*p*-toluenesulfinyl)furan, **16e**.

From racemic α -hydroxy sulfinyl diene **2e** (105 mg, 0.33 mmol) in 6.6 mL of CH₂Cl₂ bubbling O₃/O₂ (10 min) and with SMe₂, according to the general procedure, sulfinyl furan **16e** (59 mg, 59%) was obtained as a colorless oil after chromatography (10-40% EtOAc-hexane).

Data for **16e**: $R_f = 0.24$ (40% EtOAc-hexane). $^1\text{H NMR}$ (300 MHz) δ 2.38 (s, 3 H, CH₃ *p*Tol), 6.41 (d, 1 H, $J = 2.0$ Hz, H-4), 7.17 (t, 2 H, $J = 8.5$ Hz, 2 H_{*m*} *p*FPh), 7.29 (d, 2 H, $J = 7.8$ Hz, 2 H_{*m*} *p*Tol), 7.38 (d, 1 H, $J = 2.0$ Hz, H-5), 7.51 (d, 2 H, $J = 8.3$ Hz, 2 H_{*o*} *p*Tol), 7.87 (dd, 2 H, $J = 8.9, 5.2$ Hz, 2 H_{*o*} *p*FPh). $^{13}\text{C NMR}$ (75 MHz) δ 21.8 (CH₃ *p*Tol), 110.0 (C-4), 116.3, 116.6, 124.8 (2 C), 129.5, 129.6, 130.3 (2 C), 142.9, 154.6. **IR** (film): 3115, 3049, 2925, 2851, 1518, 1489, 1237, 1161, 1085, 1048, 1014, 887, 839, 811 cm⁻¹. **MS** (ES): 623 [2M+Na]⁺, 601 [2M+H]⁺, 323 [M+Na]⁺, 301 [M+H]⁺ (100%).

Synthesis of (–)-(*S*)-2-(*t*-Butyldiphenylsilyloxy)methyl-3-(*p*-toluenesulfinyl)furan, **16g**.

From α -hydroxy sulfinyl diene **2g** (128 mg, 0.26 mmol) in 5 mL of CH₂Cl₂ bubbling O₃/O₂ (5 min) and with SMe₂, according to the general procedure, sulfinyl furan **16g** (70 mg, 56%) was obtained as a colorless oil after chromatography (0-50% EtOAc-hexane).

Data for **16g**: $R_f = 0.35$ (50% EtOAc-hexane). $[\alpha]^{20}_{\text{D}} = -107.8$ ($c = 3.7$). $^1\text{H NMR}$ (300 MHz) δ 1.06 (s, 9 H, 3 CH₃ *t*-Bu), 2.37 (s, 3 H, CH₃ *p*Tol), 4.81 (d, 1 H, $J = 13.3$ Hz, CH₂-OTBDPS), 4.91 (d, 1 H, $J = 13.3$ Hz, CH₂-OTBDPS), 6.30 (d, 1 H, $J = 2.0$ Hz, H-4), 7.24 (d, 2 H, $J = 8.0$ Hz, 2 H_{*m*} *p*Tol), 7.31 (d, 1 H, $J = 2.0$ Hz, H-5), 7.35-7.46 (m, 8 H), 7.68-7.71 (m, 4 H). $^{13}\text{C NMR}$ (75 MHz) δ 19.2, 21.3, 26.7 (3 C), 56.9

(C-2'), 107.5, 124.3 (2 C), 127.3, 127.8 (4 C), 129.8 (2 C), 129.92, 129.94, 132.5, 132.7, 135.6 (2 C), 135.63 (2 C), 140.9, 141.0, 143.3, 155.4. **IR** (film): 3069, 3044, 2956, 2930, 2856, 1589, 1508, 1489, 1471, 1428, 1387, 1128, 1107, 1088, 1052, 823, 811, 703 cm⁻¹. **MS** (ES): 971 [2M+Na]⁺, 497 [M+Na]⁺, 475 [M+H]⁺, 397 [M-Ph]⁺ (100%).

Synthesis of (±)-2-Ethyl-3-(*p*-toluenesulfinyl)-5-methylfuran, **16h**.

From racemic α -hydroxy sulfinyl diene **2h** (64 mg, 0.24 mmol) in 5 mL of CH₂Cl₂ bubbling O₃/O₂ (3 min) and with SMe₂ (2 mL, 27.2 mmol, 105 equiv) according to the general procedure, sulfinyl furan **16h** (31 mg, 52%) was obtained as a colorless oil after chromatography (10-50% EtOAc-hexane). During the purification 12 mg (18%) of the oxidation product **17h** (colorless oil) and 6 mg of the mixture of both products were also isolated.

Data for **16h**: *R_f* = 0.18 (50% EtOAc-hexane). **¹H NMR (300 MHz)** δ 1.30 (t, 3 H, *J* = 7.6 Hz, CH₃), 2.10 (s, 3 H, CH₃ *p*Tol), 2.30 (s, 3 H, CH₃), 2.86 (q, 2 H, *J* = 7.5 Hz, CH₂), 5.70 (s, 1 H, H-4), 7.25 (d, 2 H, *J* = 8.5 Hz, 2 H_{*m*} *p*Tol), 7.45 (d, 2 H, *J* = 8.3 Hz, 2 H_{*o*} *p*Tol). **¹³C NMR (75 MHz)** δ 13.2 (CH₃), 13.4 (CH₃), 20.1 (CH₃ *p*Tol), 21.3 (CH₂ Et), 102.7 (C-4), 124.19 (2 C_{*o*} *p*Tol), 124.25 (C-3), 129.7 (2 C_{*m*} *p*Tol), 140.6 (C_{*ipso*} *p*Tol), 141.1 (C_{*p*} *p*Tol), 152.2 (C-5), 159.1 (C-2). **IR** (film): 3115, 3047, 2976, 2922, 2872, 1605, 1573, 1490, 1455, 1382, 1348, 1211, 1124, 1088, 1046, 1033, 1015, 940, 811 cm⁻¹. **MS** (ES): 519 [2M+Na]⁺, 271 [M+Na]⁺, 249 [M+H]⁺ (100%).

Partial data for **17h**: *R_f* = 0.25 (50% EtOAc-hexane). **¹H NMR (300 MHz)** δ 1.20 (t, 3 H, *J* = 7.6 Hz, CH₃), 2.20 (s, 3 H, CH₃ *p*Tol), 2.39 (s, 1 H, CH₃), 2.92 (q, 2 H, *J* = 7.5 Hz, CH₂), 6.15 (s, 1H, H-4), 7.30 (d, 2 H, *J* = 8.5 Hz, 2 H_{*m*} *p*Tol), 7.78 (d, 2 H, *J* = 8.3 Hz, 2 H_{*o*} *p*Tol).

Acknowledgements

This research was supported by grants CTQ2009-07752 and CTQ2016-77555-C2-2-R. We thank CSIC-FSE for a doctoral fellowship to A.C. and a postdoctoral contract to I.O.

References

¹ For leading reviews, see: (a) Colomer, I.; Velado, M.; Fernández de la Pradilla, R.; Viso, A. *Chem. Rev.* **2017**, *117*, 14201–14243. (b) Choppin, S.; Ferreiro-Medeiros, L.; Barbarottoa, M.; Colobert, F. *Chem. Soc. Rev.* **2013**, *42*, 937–949. (c) Smith, L. H. S.; Coote, S. C.; Sneddon, H. F.; Procter, D. J. *Angew. Chem. Int. Ed.* **2010**, *49*, 5832–5844. (d) Carreño, M. C.; Hernández-Torres, G.; Ribagorda, M.; Urbano, A. *Chem. Commun.* **2009**, 6129–6144. (e) Fascione, M. A.; Brabham, R.; Turnbull, W. B. *Chem. Eur. J.* **2016**, *22*, 3916–3928.

² For recent contributions on this field, see: (a) Dherbassy, Q.; Djukic, J.-P.; Wencel-Delord, J.; Colobert, F. *Angew. Chem. Int. Ed.* **2018**, *57*, 4668–4672. (b) Meidlinger, D.; Marx, L.; Bordeianu, C.; Choppin, S.; Colobert, F.; Speicher, A. *Angew. Chem. Int. Ed.* **2018**, *57*, 9160–9164. (c) Gerlinger, C. K. G.; Kreger, S.; Gaich, T. *Chem. Eur. J.* **2018**, *24*, 3994–3997. (d) Rodríguez, R. I.; Ramírez, E.; Fernández-Salas, J. A.; Sánchez-Obregón, R.; Yuste, F.; Alemán, J. *Org. Lett.* **2018**, *20*, 8047–8051. (e) Kaldre, D.; Klose, I.; Maulide, N. *Science* **2018**, *361*, 664–667. (f) Yanagi, T.; Nogi, K.; Yorimitsu, H. *Tetrahedron Lett.* **2018**, *59*, 2951–2959. (g) Aukland, M. H.; Talbot, F. J. T.; Fernández-Salas, J. A.; Ball, M.; Pulis, A. P.; Procter, D. J. *Angew. Chem. Int. Ed.* **2018**, *57*, 9785–9789.

³ (a) Colomer, I.; Gheewala, C.; Simal, C.; Velado, M.; Fernández de la Pradilla, R.; Viso, A. *J. Org. Chem.* **2016**, *81*, 4081–4097. (b) Simal, C.; Bates, R. H.; Ureña, M.; Giménez, I.; Koutsou, C.; Infantes, L.; Fernández de la Pradilla, R.; Viso, A. *J. Org. Chem.* **2015**, *80*, 7674–7692. (c) Fernández de la Pradilla, R.; Velado, M.; Colomer, I.; Simal, C.; Viso, A.; Gornitzka, H.; Hemmert, C. *Org. Lett.* **2014**, *16*, 5200–5203. (d) Viso, A.; Fernández de la Pradilla, R.; Ureña, M.; Bates, R.; del Águila, M. A.; Colomer, I. *J. Org. Chem.* **2012**, *77*, 525–542. (e) Fernández de la Pradilla, R.; Tortosa, M.; Castellanos, E.; Viso, A.; Baile, R. *J. Org. Chem.* **2010**, *75*, 1517–1533. (f) Fernández de la Pradilla, R.; Montero, C.; Tortosa, M.; Viso, A. *Chem. Eur. J.* **2009**, *15*, 697–709. (g) Fernández de la Pradilla, R.; Lwoff, N.; del Águila, M. A.; Tortosa, M.; Viso, A. *J. Org. Chem.* **2008**, *73*, 8929–8941.

⁴ For related efforts of our group, see: (a) Fernández de la Pradilla, R.; Castellanos, A.; Fernández, J.; Lorenzo, M.; Manzano, P.; Méndez, P.; Priego, J.; Viso, A. *J. Org. Chem.* **2006**, *71*, 1569–1575. (b) Fernández de la Pradilla, R.; Méndez, P.; Viso, A. *Tetrahedron Lett.* **2000**, *41*, 2871–2874.

⁵ For reviews on the synthesis of carbohydrate derivatives from acyclic precursors, see: (a) Ager, D. J.; East, M. B. *Tetrahedron* **1993**, *49*, 5683–5765. (b) Ager, D. J.; East, M. B. *Tetrahedron* **1992**, *48*, 2803–2894.

⁶ Prepared in one step by the procedure of Craig: Craig, D.; Daniels, K.; McKenzie, A. R. *Tetrahedron* **1993**, *49*, 11263–11304.

⁷ Massad, S. K.; Hawkins, L. D.; Baker, D. C. *J. Org. Chem.* **1983**, *48*, 5180–5182.

⁸ (a) Posner, G. H.; Mallamo, J. P.; Miura, K.; Hulce, M. *Pure Appl. Chem.* **1981**, *53*, 2307–2314. (b) Cheng, H.-C.; Yan, T.-H. *Tetrahedron Lett.* **1990**, *31*, 673–676. (c) Solladié, G.; Moine, G. *J. Am. Chem. Soc.* **1984**, *106*, 6097–6098. (d) Fawcett, J.; House, S.; Jenkins, P. R.; Lawrence, N. J.; Russell, D. R. *J. Chem. Soc., Perkin Trans. 1* **1993**, 67–73. (e) Fernández de la Pradilla, R.; Castellanos, A.; Osante, I.; Colomer, I.; Sánchez, M. I. *J. Org. Chem.* **2009**, *74*, 170–181. (f) See reference 9 in: Fernández de la

Pradilla, R.; Manzano, P.; Montero, C.; Priego, J.; Martínez-Ripoll, M.; Martínez-Cruz, L. A. *J. Org. Chem.* **2003**, *68*, 7755–7767.

⁹ (a) Mirabella, S.; Cardona, F.; Goti, A. *Org. Biomol. Chem.* **2016**, *14*, 5186–5204. (b) Lenci, E.; Menchi, G.; Trabocchi, A. *Org. Biomol. Chem.* **2016**, *14*, 808–825.

¹⁰ For a related application of carbamates to the synthesis of aminocarbohydrates, see: Roush, W. R.; Follows, B. C. *Tetrahedron Lett.* **1994**, *35*, 4935–4938.

¹¹ For additions of nucleophiles to carbohydrate derived alkenyl sulfoxides and especially sulfones, see: (a) Dey, D.; Bhaumik, A.; Pathak, T. *Tetrahedron* **2013**, *69*, 8705–8712. (b) Atta, A. K.; Dey, D.; Bhaumik, A.; Manna, C.; Pal, T. K.; Pathak, T. *Eur. J. Org. Chem.* **2012**, 5010–5017. (c) Pathak, T.; Bhattacharya, R. *Carbohydrate Res.* **2008**, *343*, 1980–1998. (d) Pathak, T. *Tetrahedron* **2008**, *64*, 3605–3628. The intermolecular addition of amines to sulfonyl dihydrofurans has been studied in our group, see: (e) Fernández de la Pradilla, R.; Manzano, P.; Viso, A.; Fernández, J.; Gómez, A. *Heterocycles* **2006**, *68*, 1429–1442.

¹² Hirama, M.; Hioki, H.; Itô, S.; Kabuto, C. *Tetrahedron Lett.* **1988**, *29*, 3121–3124.

¹³ Hirama, M.; Hioki, H.; Itô, S.; Kabuto, C. *Tetrahedron Lett.* **1988**, *29*, 3125–3127.

¹⁴ For reviews on the Pummerer rearrangement, see: (a) Shafir, A. *Tetrahedron Lett.* **2016**, *57*, 2673–2682. (b) Pulis, A. P.; Procter, D. J. *Angew. Chem. Int. Ed.* **2016**, *55*, 9842–9860. (c) Smith, L. H. S.; Coote, S. C.; Sneddon, H. F.; Procter, D. J. *Angew. Chem. Int. Ed.* **2010**, *49*, 5832–5844. (d) Akai, S.; Kita, Y. *Top. Curr. Chem.* **2007**, *274*, 35–76. (e) Feldman, K. S. *Tetrahedron* **2006**, *62*, 5003–5034. (f) Bur, S. K.; Padwa, A. *Chem. Rev.* **2004**, *104*, 2401–2432.

¹⁵ For selected reviews see: (a) Hou, X.-L.; Yang, Z.; Wong, H. N. C. *Prog. Heterocycl. Chem.* **2003**, *15*, 167–205. (b) Keay, B. A.; Dibble, P. *Comprehensive Heterocyclic Chemistry II* **1997**, *2*, 395–436.

¹⁶ (a) Lipshutz, B. H. *Chem. Rev.* **1986**, *86*, 795–819. (b) Wong, H. N. C.; Yu, P.; Yick, C.-Y. *Pure Appl. Chem.* **1999**, *71*, 1041–1044. (c) Lee, H.-K.; Chan, K.-F.; Hui, C.-W.; Yim, H.-K.; Wu, X.-W.; Wong, H. N. C. *Pure Appl. Chem.* **2005**, *77*, 139–143. (d) Padwa, A.; Zhang, H. *J. Org. Chem.* **2007**, *72*, 2570–2582.

¹⁷ Wright, D. L. *Prog. Heterocycl. Chem.* **2005**, *17*, 1–32.

¹⁸ For reviews, see: (a) Brown, R. C. D. *Angew. Chem., Int. Ed.* **2005**, *44*, 850–852, and references cited therein. (b) Kirsch, S. F. *Org. Biomol. Chem.* **2006**, *4*, 2076–2080. (c) Blanc, A.; Bénateau, V.; Weibel, J.-M.; Pale, P. *Org. Biomol. Chem.* **2016**, *14*, 9184–9205.

¹⁹ Minetto, G.; Raveglia, L. F.; Sega, A.; Taddei, M. *Eur. J. Org. Chem.* **2005**, 5277–5288.

²⁰ Mross, G.; Holtz, E.; Langer, P. *J. Org. Chem.* **2006**, *71*, 8045–8049.

²¹ (a) Arai, Y.; Masuda, T.; Masaka, Y.; Shiro, M. *J. Chem. Soc., Perkin Trans. 1* **1996**, 759–762. (b) Girodier, L. D.; Rouessac, F. P. *Tetrahedron: Asymmetry* **1994**, *5*, 1203–1206. (c) Arai, Y.; Masuda, T.; Masaki, Y. *Synlett* **1997**, 1459–1461. (d) Arai, Y.; Suzuki, A.; Masuda, T.; Masaki, Y.; Shiro, M. *J. Chem. Soc., Perkin Trans. 1* **1995**, 2913–2917. (e) Girodier, L. D.; Maignan, C. S.; Rouessac, F. P. *Tetrahedron: Asymmetry* **1995**, *6*, 2045–2052. (f) Arai, Y.; Masuda, T.; Masaki, Y.; Koizumi, T. *Heterocycles* **1994**, *38*, 1751–1756. (g) Arroyo, Y.; Carreño, M. C.; García-Ruano, J. L.; Rodríguez-Amo, J. F.; Santos, M.; Sanz-Tejedor, M. A. *Tetrahedron: Asymmetry* **2000**, *11*, 1183–1191. (h) Arai, Y.; Masuda, T.; Masaki, Y. *Chem. Pharm. Bull.* **1998**, *46*, 1078–1083. (i) Arai, Y.; Masuda, T.; Masaki, Y.; Shiro, M. *Tetrahedron: Asymmetry* **1996**, *7*, 1199–1204.

²² Fernández de la Pradilla, R.; Fernández, J.; Viso, A.; Fernández, J.; Gómez, A. *Heterocycles* **2006**, *68*, 1579–1584.