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Synthesis of substituted α,β-unsaturated δ-lactones from vinyl tellurides

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ABSTRACT

A new approach for the synthesis of α,β-unsaturated δ-lactones, a unit present in many natural products with interesting biological activities is described. The approach was based on the use of a vinyl telluride, and it is complementary to the methods using ring-closing metathesis. The sequence was performed in good overall yield with retention of the *Z*-double bond geometry.

1. Introduction

Substituted α,β-unsaturated δ-lactones units are present in a large number of compounds isolated from plants and marine organisms. Representative examples are goniothalamin,[1] massoialactone,[2] and euscapholide[3] (Fig. 1). These compounds possess a broad range of biological activities. Noteworthily, structure–activity relationships have demonstrated that the α,β-unsaturated-δ-lactone moiety plays a key role in the bioactivity of many natural products. This is due to the fact that this unit is an excellent potential Michael acceptor for nucleophilic amino acid residues of the natural receptors interacting with these compounds.[4–6]

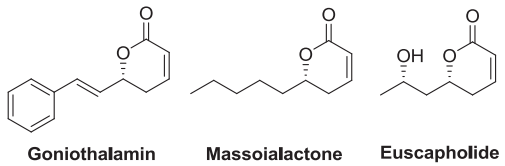


Fig. 1. Natural products containing α,β-unsaturated δ-lactones units.

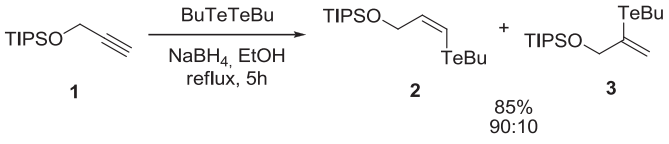
Because of their biological activities, many approaches to these lactones have been reported.[7] The majority of them are based on ring-closing metathesis strategies,[8] which has become a powerful tool in organic synthesis for the preparation of cyclic compounds from diolefinic precursors.[9]

In the current decade, organotellurium compounds have attained remarkable development as *synthons* in synthetic organic chemistry.[10] In addition, some organotellurium compounds are potent in vitro antioxidants,[11] showing very low toxicity, as well no neurotoxic effects.[11b,12]

Allylic alcohols containing a stereodefined double bond are important synthetic intermediates,[13] and can be easily prepared when hydroxy-alkynes are subjected to hydrotelluration conditions.[14] Recently, we demonstrated the efficiency of TIPS as the protecting group of propargyl and homo-propargyl alcohols in order to improve the regioselectivity in the hydrotelluration reaction.[15] In this paper we describe the use of organotellurium compounds on the synthesis of substituted α,β-unsaturated δ-lactones.

2. Results and discussion

In an initial approach propargyl alcohol was converted into its TIPS, 1, derivative according to the literature procedure[16] and then subjected to hydrotelluration conditions to yield the corresponding vinyl tellurides **2** and **3**,[15] which were easily separated by flash column chromatography (Scheme 1).



Scheme 1.

The influence of the TIPS group was remarkable. When propargyl alcohol was used as the alkyne source a 56:44 mixture of regioisomers was observed. The regioisomeric ratio was determined by ^{1}H NMR and confirmed by ^{125}Te NMR and gas chromatography.

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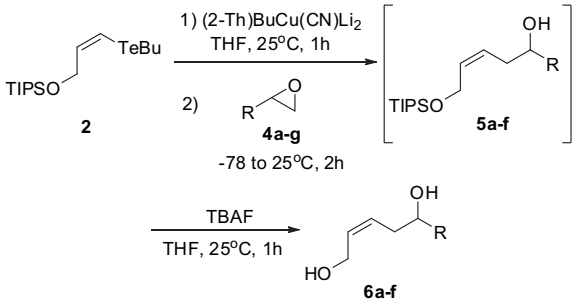
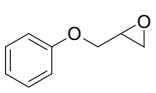
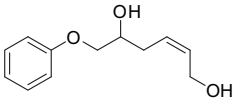
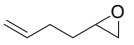
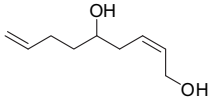
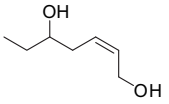
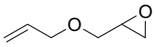
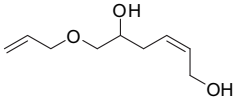
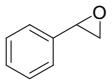
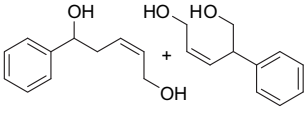
In spite of the widespread use of bulky groups in organic chemistry, there are few attempts at quantifying the intuitive concept of bulkiness.[17] The screening action of a bulky group on an atom could be described by an angle.[18] This concept of cone angle was applied to silyl groups and the cone angle found for TIPS, θ=160°.[19] In other words, the bulkiness of TIPS seems to be of the correct magnitude as to exhibit a good compromise between useful steric effects to give the desired regioisomer rather than electronic factors.

Table 1
Synthesis of 1,5-diols from the reaction of **2**/(2-Th)BuCu(CN)Li_2 system with epoxides followed by deprotection



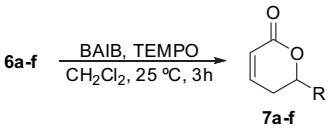
	Epoxide	1,5-Diol	Yield[a] (%)
1	 **4a**	 **6a**	70
2	 **4b**	 **6b**	71
3	 **4c**	 **6c**	70
4	 **4d**	 **6d**	73
5	 **4e**	 **6e + 6f**	65
6	 **4f**	—	—[b]
7	 **4g**	—	—[b]

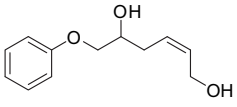
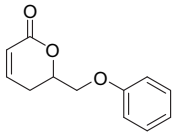
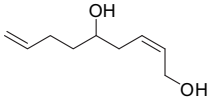
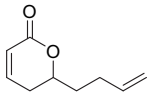
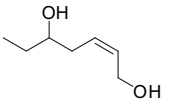
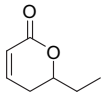
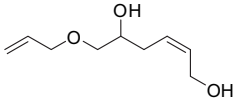
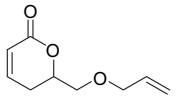
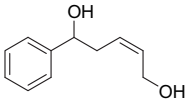
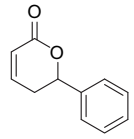
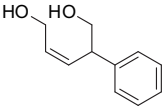
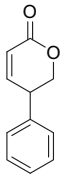
[a] Overall yield after two steps.
[b] No reaction was observed.

The vinyl telluride **2** was then transformed into the corresponding *Z* higher order vinyl cyanocuprate by the reaction with (2-Th)BuCu(CN)Li_2 with total retention of the double-bond configuration.[20] The reaction of the resulting higher order vinyl cyanocuprate intermediate with epoxides **4a**–**e** gave the corresponding homoallylic alcohols **5a**–**f**. The crude product was treated with TBAF in THF[21] to give the corresponding 1,5-diols **6a**–**f** in good yields after purification by chromatographic column (Table 1).

In all cases the homoallylic alcohols **6a**–**f** corresponding of the attack to the less-substituted carbon atom were obtained. The exception was the reaction with styrene oxide, **4e**, which led to a separable mixture of the regioisomeric diols **6e** and **6f** in a 1.2:1 ratio (Table 1, entry 5). When disubstituted epoxides **4f** and **4g** were used, the corresponding products were not observed, even in the presence of $BF_3 \cdot Et_2O$, probably due to the steric effects. The relative volatile and non-polar byproduct containing tellurium formed in the reaction was removed from the reaction mixture by flash

Table 2
Synthesis of α,β-unsaturated δ-lactones **7a**–**f**



	1,5-Diol	Lactone	Yield[a] (%)
1	 **6a**	 **7a**	65
2	 **6b**	 **7b**	60
3	 **6c**	 **7c**	75
4	 **6d**	 **7d**	75
5	 **6e**	 **7e**	50
6	 **6f**	 **7f**	70

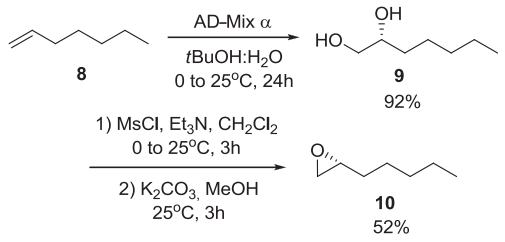
[a] Isolated yield.

chromatography or by conversion into the methyl di-*n*-butyltelluronium iodide.[22]

Several conditions have been described to oxidize 1,5-diols into the corresponding δ-lactones. These conditions, however, led to the formation of undesired ketoaldehyde or as a side product, resulting in lower yields of the corresponding lactones.[23] Thus, **6a**–**f** were submitted to a more selective oxidative method based on the use of bis-acetoxyiodobenzene (BAIB) and a catalytic amount of 2,2,6,6-tetramethyl-1-piperidinyloxy (TEMPO).[24] The products corresponding to the oxidation of primary allylic diol **7a**–**f** were obtained in moderate to good yield. The results are depicted in Table 2.

The method was then applied to the synthesis of (*R*)-Massoialactone, a natural product isolated from the bark of *Cryptocarya massoia*[2] and used as a constituent of native medicines. This compound was later isolated as a defense substance of two species of formicine ants of the genus *Camponutus*[25] and as a flavor substance from cane molasses[26] and tuberose flowers.[27] It is a powerful skin irritant and produces systolic standstill in frog heart muscles.[28]

Sharpless asymmetric dihydroxylation[29] of commercially available 1-heptene **8** under 'standard conditions' using AD-mix α gave the desired diol **9** in 92% isolated yield after chromatography and in a 88% ee by di-Mosher ester formation.[30] Treatment of diol 9 with mesyl chloride (1 equiv) followed by the reaction with K_2CO_3 in MeOH gave epoxide 10 in moderate yield (Scheme 2).[31]

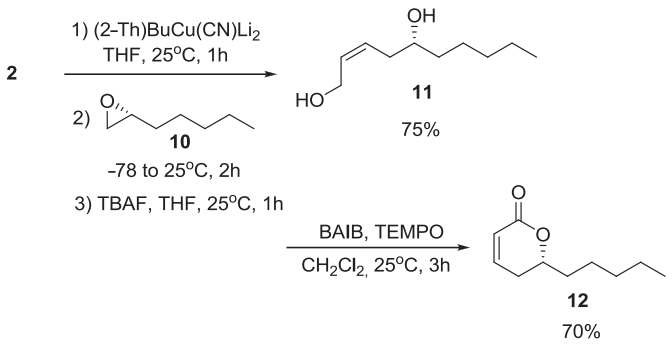


Scheme 2.

The absolute configuration of the obtained epoxide **10** was assigned by comparison of the measured optical rotation value with that of the literature data.[32]

Thus, transmetalation of vinyl telluride **2** with (2-Th)BuCu(CN)Li_2 followed by the capture of the mixed cuprate with epoxide **10** and subsequent deprotection gave 11 in 75% overall yield. Further oxidation gave (*R*)-Massoialactone **12** in 70% yield (Scheme 3).

(*R*)-Massoialactone was obtained in 52% overall yield after three steps and the methodology shows efficiency when compared with other previously described methodologies.[7b,33]



Scheme 3.

3. Conclusion

In conclusion, the method demonstrates to be useful for the synthesis of α,β-unsaturated δ-lactones starting from vinyl tellurides. The approach is complementary to the methods using RCM reactions and the sequence was performed in good overall yield with retention of the double bond geometry. Finally, the method offers future possibilities in the development of new organometallic approaches to the compounds containing *Z*-double bonds.

4. Experimental section

4.1. Material

All reagents and solvents used were previously purified and dried in agreement with the literature.[34] THF was distilled from sodium/benzophenone under N_2 immediately before use. *n*-BuLi was titrated using 1,10-phenanthroline as indicator prior to use.[35] All operations were carried out in flame-dried glassware. Reactions were monitored by thin-layer chromatography on 0.25 mm E. Merck silica gel 60 plates (F_{254}) using UV light, vanillin and *p*-anisaldehyde as visualizing agents. Column chromatographic purification was performed using Silica Gel 60 (230–400 mesh) unless indicated otherwise. All compounds purified by chromatography were sufficiently pure for use in further experiments, unless indicated otherwise.

4.2. Instrumentation

^{1}H NMR data were recorded at 300 MHz using a Varian UNITY PLUS spectrometer. ^{1}H NMR chemical shifts are reported as delta (δ) units in parts per million (ppm) relative to residual $CDCl_3$ (7.26 ppm). Coupling constants (J) were reported in hertz (Hz). ^{13}C NMR data were recorded at 75 MHz using a Varian UNITY PLUS spectrometer. ^{13}C NMR chemical shifts were reported as delta (δ) units in parts per million (ppm) relative to the central line of $CDCl_3$ (77.0 ppm). ^{125}Te NMR data were obtained at 94.6 MHz using diphenyl ditelluride as an external reference (422.0 ppm). Typical parameters were as follows: acquisition time equal to 0.64 s, pulse of 45°, spectral window of 43.9 kHz; and line broadening equal to 5.0 Hz; a good compromise value because although a greater line broadening would improve the signal-to-noise ratio of the tellurium spectra, which would also imply in less signal resolution.

Low resolution mass spectra were obtained using a Shimadzu QP-5050A Spectrometer (70 eV) using helium 4.5 as a carrier gas and a DB-5 column (30 m×0.25 μm). High resolution mass spectra were obtained by the São Paulo University, Chemistry Institute mass spectrometry facility, run by the electro spray ionization time-of-flight (ESI-TOF) mode on a Bruker Micro Tof Ic Bruker Daltonics mass spectrometer.

Infra-red spectra were recorded using FT/IR spectrometer Bruker IFS 66 and the samples were prepared as thin films on salt plates or as KBr pellets. The melting points (mp) were obtained using a Eletrothermal 9100 melting point apparatus and are not corrected.

4.3. Typical procedure

4.3.1. Preparation of dibutylditelluride. A 2 L round-bottomed flask equipped with a 250 mL pressure equalized dropping funnel was charged with tellurium metal (20.1 g, 157 mmol) [dried prior to use in an 85 °C oven], dry THF (1 L) and cooled to 0 °C. The addition funnel was charged with *n*-butyllithium (180 mmol, 72 mL of a 2.5 M solution in hexanes). The *n*-butyllithium was added dropwise. After the addition was completed, the ice bath was removed and the reaction mixture was stirred at room temperature for 1 h. A

saturated solution of NH_4Cl (250 mL) was then slowly added. The reaction was stirred at room temperature for about 3 h while open to the atmosphere (O_2). The organic layer was isolated and the aqueous layer was extracted with EtOAc (2×150 mL). The combined organic phases were dried over $MgSO_4$ and filtered through a pad of Celite. Concentration in vacuo provided 50.7 g (87%) of dibutylditelluride as a red oil, which was used directly without further purification. IR (thin film) ν_{max} 2955, 2921, 2868, 1457, 1175 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 3.10 (t, J=7.80 Hz, 4H, 2×CH_2), 1.80–1.60 (m, 4H, 2×CH_2), 1.46–1.30 (m, 4H, 2×CH_2), 0.92 (t, J=7.50 Hz, 6H, 2×CH_3); ^{13}C NMR (75 MHz, $CDCl_3$) δ 35.6 (2×CH2), 24.5 (2×CH_2), 13.3 (2×CH_2), 4.2 (2×CH_3).

*4.3.2. Preparation of triisopropyl(prop-2-ynyloxy)silane (**1**).* To a round-bottomed flask under argon were added CH_2Cl_2 (30 mL), imidazole (1.70 g, 25 mmol), and propargyl alcohol (0.56 g, 0.58 mL, 10 mmol) the mixture was cooled to 0 °C and TIPSCl (2.30 g, 2.55 mL, 12 mmol) was slowly added. The mixture was stirred for 12 h, diluted with CH_2Cl_2 (20 mL) and quenched with H_2O (20 mL). The organic phase was washed with 3% HCl (10 mL), saturated $NaHCO_3$ (20 mL), and finally H_2O. The organic phase was then dried over $MgSO_4$, filtered, and concentrated in vacuo. The pure silyl ether was distilled from the residue under reduced pressure (bp 110 °C, 20 mmHg) to yield 2.0 g (95%) of the title compound. ^1H NMR (300 MHz, $CDCl_3$) δ 4.37 (d, J=2.4 Hz, 2H, CH_2), 2.38 (t, J=2.7 Hz, 1H, CCH), 1.11–1.04 (m, 3H, 3×CH, 18H, 6×CH_3); ^{13}C NMR (75 MHz, $CDCl_3$) δ 81.4 (CH×CCH_2), 72.5 (CH≡CCH_2), 51.7 (CH_2), 17.8 (6×CH_3), 11.9 (3×CH).

*4.3.3. Preparation of (Z)-(3-(butyltellanyl)allyloxy)triiso-propylsilane (**2**).* Compound **1** (19.0 g, 90 mmol) and dibutylditelluride (16.8 g, 45 mmol) were dissolved in absolute ethanol (100 mL) at room temperature. Finely powdered sodium borohydride was added in portions to the above solution. Additional sodium borohydride was added as necessary to maintain a yellow color (indicative of the butyltellurolate anion). The solution was heated to reflux for 5 h and cooled to room temperature. The reaction mixture was then poured into a saturated solution of $NaHCO_3$ (200 mL) and diluted with EtOAc (200 mL). The organic layer was isolated and washed with H_2O (500 mL), and brine (500 mL) before drying over $MgSO_4$. The organic phase was filtered and concentrated in vacuo. Silica gel chromatography using hexanes provided 30.6 g (85%) of the title compound as a yellow oil. IR (thin film) ν_{max} 2941, 2865, 1462, 1095, 918 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 6.72 (dt, J=9.9, 1.5 Hz, 1H, TeCH=CH), 6.39 (dt, J=9.9, 5.1 Hz, 1H, TeCH=CH), 4.22 (dd, J=5.1, 1.5 Hz, 2H, CH=CHCH_2), 2.7 (t, J=7.8 Hz, 2H, CH_2), 1.90–1.60 (m, 2H, CH_2), 1.46–1.20 (m, 2H, CH_2), 1.20–1.00 (m, 3H, 3×CH, 18H, 6×CH_3), 0.92 (t, J=7.50 Hz, 3H, CH_3); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.1 (TeCH=CH), 102.1 (TeCH=CH), 65.7 (CH=$CH$$CH_2$), 33.8 ($CH_2$), 24.9 ($CH_2$), 17.5 (6×$CH$$CH_3$), 17.4 ($CH_2$), 13.5 ($CH_3$), 11.9 (3×$CH$$CH_3$); ^{125}Te NMR (94.6 MHz, $CDCl_3$) δ 298.6; GC–MS (EI, rel int. %) m/z 400 ([M^+], 6), 357 (83), 245 (41), 227 (12), 213 (29), 169 (100), 157 (24), 127 (60), 87 (10), 57 (7); HRMS (ESI, MeOH/H_2O) calcd for $C_{16}H_{34}OSiTe$ [M+H]$^+$, 401.1519; found 400.9330.

4.4. General procedure for the synthesis of 1,5-diols (6a–f) from the reaction of 2/(2-Th)BuCu(CN)Li_2 system with epoxides 4a–f followed by deprotection

To a flask equipped with a stirring bar and a rubber septum under argon atmosphere was added anhydrous THF (10 mL) and distilled thiophene (1.05 g, 12.5 mmol). The solution was cooled to −78 °C and *n*-butyllithium in hexanes (1.40 M, 9.0 mL, 12.5 mmol) was added dropwise. The resulting light-yellow solution was warmed to −40 °C and kept for 20 min. After that, this solution was transferred via canula to a suspension of CuCN (0.89 g, 10 mmol) in THF previously cooled at −78 °C. At the end of the addition, the acetone/dry ice bath was exchanged for an ice bath. After 5 min the flask was again placed in a dry ice/acetone bath and *n*-butyllithium in hexanes (1.40 M, 7.10 mL, 10 mmol) was added dropwise. The solution was maintained at this temperature for 15 min. The solution was then warmed up to 0 °C and the vinylic telluride **2** (4.20 g, 10.5 mmol) dissolved in THF (10 mL) was added. After being stirred for 1 h at room temperature, the mixture was cooled to −78 °C and the appropriate epoxide **4a-g** (10 mmol) in THF (10 mL) was added. The reaction mixture was warmed to 0 °C. After 3 h at 0 °C, it was warmed to ambient temperature and stirred for an additional 1 h. The reaction mixture was then cooled to −78 °C and a solution of saturated NH_4Cl and aqueous NH_4OH (9:1) was added. The mixture was stirred for 15 min while the temperature of the system was allowed to rise. After that, the mixture was extracted with EtOAc (2×60 mL). The organic layer was washed with brine (2×100 mL). The combined organic layers were dried over $MgSO_4$ and concentrated in vacuo. The crude silyl ether **5a–f** was dissolved in THF (5 mL) and TBAF (10 mL, 1 M solution in THF, 10 mmol) was added dropwise. The reaction was monitored by TLC. The reaction was then quenched by the addition of a saturated solution of NH_4Cl (10 mL). The aqueous layer was extracted with EtOAc and the combined organic phases were washed with brine, dried over $MgSO_4$, filtered, and concentrated in vacuo. The crude product was purified by chromatography on silica gel using hexanes/EtOAc (50:50) to yield the corresponding 1,5-diols, **6a–f**.

*4.4.1. (Z)-6-Phenoxyhex-2-ene-1,5-diol (**6a**).* Isolated as a colorless oil; 1.45 g (70%); IR (KBr pellet) ν_{max} 3330 (OH), 2926, 2875, 1598, 1495,1292, 1244, 1078, 754 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.34–7.25 (m, 2H, 2×Ar–CH), 7.02–6.89 (m, 3H, 3×Ar–CH), 5.96–5.83 (m, 1H, CH=CH), 5.73–5.61 (m, 1H, CH=CH), 4.26–4.18 (m, 1H, CHOH), 4.15–4.01 (m, 2H, CHOHCH_2), 4.00–3.87 (m, 2H, CH_2CH=CH), 3.11 (br s, 2H, 2×OH), 2.54–2.34 (m, 2H, CH=CHCH_2); ^{13}C NMR δ (75 MHz, $CDCl_3$) δ 158.3 (C^q–Ar), 131.6 (*C*H=CH), 129.5 (CH=*C*H), 128.2 (2×CH–Ar), 121.1 (CH–Ar), 114.4 (2×CH–Ar), 71.2 (CHOHCH_2), 68.9 (CHOH), 57.4 (CH_2CH=CH), 31.0 (CH=CHCH_2); GC–MS (EI, rel int. %) m/z 208 ([M^+], 3), 154, 136 (20), 119 (12), 108 (35), 94 (100), 77 (45), 65 (18), 55 (44), 51 (19), 43(38), 41 (26); HRMS (ESI, MeOH/H_2O) calcd for $C_{12}H_{16}O_3Na$ [M+Na]$^+$, 231.0997; found 231.0991.

*4.4.2. (Z)-Nona-2,8-diene-1,5-diol (**6b**).* Isolated as a yellow oil, 1.11 g (71%); IR (KBr pellet) ν_{max} 3329 (OH), 2933, 1640, 1436, 1076, 1007, 911, 861 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.96–5.72 (m, 1H, CH=CH, 1H, CH=CH_2), 5.63–5.50 (m, 1H, CH=CH), 5.05–4.94 (m, 2H, CH=CH_2), 4.15 (dd, J=12.3, 7.2 Hz, 1H, CH_2CH=CH), 4.02 (dd, J=12.3, 6.6 Hz, 1H, CH_2CH=CH), 3.67–3.59 (m, 1H, CHOH), 3.25 (br s 2H, 2×OH), 2.32–2.03 (m, 2H, CH=CHCH_2, 2H, CH_2CH=CH_2), 1.59–1.52 (m, 2H, C$H_2$$CH_2$CH=$CH_2$); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.2 (CH=CH_2), 131.1 (CH=CH), 129.2 (CH=CH), 114.8 (CH=CH_2), 69.9 (CHOH), 57.3 (CH_2CH=CH), 35.9 (CHOHCH_2), 34.9 (CHOH$CH_2$$CH_2$), 30.05 (CH=CH$CH_2$); GC–MS (EI, rel int. %) m/z 138 (1), 83 (14), 79 (6), 71 (10), 67 (14), 54 (100), 41 (37); HRMS (ESI, MeOH/H_2O) calcd for $C_9H_{16}O_2Na$ [M+Na]$^+$, 179.1048; found 179.1051.

*4.4.3. (Z)-Hept-2-ene-1,5-diol (**6c**).* Isolated as a yellow oil, 0.91 g (70%); IR (KBr pellet) ν_{max} 3329 (OH), 3019, 2963, 2932, 2877, 1461, 1113, 1013 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.77–5.69 (m, 1H, CH=CH), 5.58–5.49 (m, 1H, CH=CH), 4.10 (dd, J=12.3, 7.2 Hz, 1H, CH_2CH=CH), 3.97 (dd, J=12.3, 7.2 Hz, 1H, CH_2CH=CH), 3.86 (br s, 2H, 2×OH), 3.52–3.44 (m, 1H, CHOH), 2.18 (t, J=7.5 Hz, 2H, CH=CHCH_2), 1.43 (qui, J=7.5 Hz, 2H, C$H_2$$CH_3$), 0.89 (t, J=7.5 Hz, 3H, CH_3); ^{13}C NMR (75 MHz, $CDCl_3$) δ 130.8 (*C*H=CH), 129.1 (CH=*C*H), 71.8 (CHOH), 57.1 (CH_2CH=CH), 34.3 (CH=CHCH_2), 29.6 ($CH_2$$CH_3$), 9.9 ($CH_2$$CH_3$); GC–MS (EI, rel int. %) m/z 130 ([M^+], 1), 83 (8), 57 (33), 54

(100), 41 (18); HRMS (ESI, MeOH/H_2O) calcd for $C_7H_{14}O_2Na$ $[M+Na]^+$, 153.0892, found 153.0899.

*4.4.4. (Z)-6-(Allyloxy)hex-2-ene-1,5-diol (**6d**).* Isolated as a yellow oil, 1.25 g (73%); IR (KBr) ν_{max} 3355 (OH), 2865, 1647, 1423, 1087, 1006, 930, 668 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.92–5.74 (m, 1H, C*H*=CH, 1H, C*H*=CH_2), 5.59–5.50 (m, 1H, CH=C*H*), 5.24 (ddd, *J*=17.0, 3.0, 1.5 Hz, 1H, CH=C*H*$_2$), 5.16 (ddd, *J*=10.8, 3.0, 1.5 Hz, 1H, CH=C*H*$_2$), 4.13 (dd, *J*=12.3, 7.5 Hz, 1H, C*H*$_2$CH=CH), 4.01 (dd, *J*=12.3, 7.5 Hz, 1H, C*H*$_2$CH=CH), 3.97 (ddd, *J*=7.2, 3.0, 1.5 Hz, 2H, C*H*$_2$CH=CH_2), 3.82–3.75 (m, 1H, C*H*OH), 3.43–3.29 (m, 2H, CHOHC*H*$_2$, 2H, 2×OH), 2.34–2.18 (m, 2H, C*H*$_2$CH=CH); ^{13}C NMR (75 MHz, $CDCl_3$) δ 134.2 (*C*H=CH_2), 131.3 (*C*H=CH), 128.7 (CH=*C*H), 117.4 (CH=*C*H$_2$), 73.7 (CHOHCH_2), 72.1 (*C*H$_2$CH=CH_2), 69.2 (CHOH), 57.3 (*C*H$_2$CH=CH), 31.0 (CH=CHCH_2); GC–MS (EI, rel int. %) *m*/*z* 136 (1), 101 (5), 83 (31), 55 (56), 54 (48), 41 (100); HRMS (ESI, MeOH/H_2O) calcd for $C_9H_{16}O_3Na$ $[M+Na]^+$,195.0997; found 195.0998.

*4.4.5. (Z)-5-Phenylpent-2-ene-1,5-diol (**6e**).* Isolated as a yellow oil, 0.62 g (35%); IR (KBr pellet) ν_{max} 3344 (OH), 3062, 2923, 1712, 1493, 1026, 760, 733, 700 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.32–7.26 (m, 5H, 5×Ar–CH), 5.77 (m, 1H, C*H*=CH), 5.53 (m, 1H, CH=C*H*), 4.64 (dd, *J*=8.1, 4.5 Hz, 1H, C*H*OH), 4.05 (dd, *J*=12.3, 7.5 Hz, 1H, C*H*$_2$CH=CH), 3.90 (dd, *J*=12.3, 6.6 Hz, 1H, C*H*$_2$CH=CH), 3.03 (br s, 2H, 2×OH), 2.62–2.51 (m, 1H, CH=CHCH_2), 2.47–2.38 (m, 1H, CH=CHCH_2); ^{13}C NMR (75 MHz, $CDCl_3$) δ 143.9 (C^q–Ar), 131.4 (*C*H=CH), 128.9 (CH=*C*H), 128.3 (2×CH–Ar), 127.5 (CH–Ar), 125.6 (2×CH–Ar), 72.7 (CHOH), 57.3 (*C*H$_2$CH=CH), 37.0 (CH=CH *C*H$_2$); GC–MS (EI, rel int. %) *m*/*z* 178 ($[M^+]$, 1), 107 (76), 106 (13), 105 (100), 79 (91), 78 (12), 77 (66), 54 (93), 51 (20); HRMS (ESI, MeOH/H_2O) calcd for $C_{11}H_{14}O_2Na$ $[M+Na]^+$ 201.0892; found 201.0896.

*4.4.6. (Z)-4-Phenylpent-2-ene-1,5-diol (**6f**).* Isolated as a yellow oil, 0.53 g (30%); IR (KBr pellet) ν_{max} 3330 (OH), 2955, 2924, 2870, 1492, 1453, 1037, 699 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.36–7.30 (m, 2H, 2×Ar–CH), 7.21–7.27 (m, 3H, 3×Ar–CH), 5.97–5.88 (m, 1H, C*H*=CH), 5.84–5.77 (m, 1H, CH=C*H*), 4.34 (ddd, *J*=12.4, 7.4, 1.4 Hz, 1H, C*H*$_2$CH=CH), 4.12 (ddd, *J*=12.4, 6.3, 0.8 Hz, 1H, C*H*$_2$CH=CH), 3.95–3.82 (m, 2H, CH_2OH), 3.73–3.66 (m, 1H, CH), 2.16 (br s, 2H, 2×OH); ^{13}C NMR (75 MHz, $CDCl_3$) δ 140.7 (C^q–Ar), 133.4 (*C*H=CH), 130.9 (CH=*C*H), 128.8 (2×CH–Ar), 127.5 (2×CH–Ar), 126.9 (CH–Ar), 66.3 (CH_2), 58.0 (*C*H$_2$CH=CH), 46.3 (CH); GC–MS (EI, rel int. %) *m*/*z* 169 (1), 130 (100), 129 (75), 128 (29), 115 (32), 91 (70), 77 (18), 51 (16), 41 (21); HRMS (ESI, MeOH/H_2O) calcd for $C_{11}H_{14}O_2Na$ $[M+Na]^+$, 201.0892; found 201.0883.

4.5. General procedure for the synthesis of α,β-unsaturated δ-lactones (7a–f) from the reaction of 1,5-diols (6a–f) with TEMPO/BAIB

To a stirred solution of the appropriate diol **6a**–**f** (2.5 mmol, 1 equiv) in CH_2Cl_2 (30 mL) was added bis-acetoxyiodobenzene (BAIB) (2.5 g, 7.7 mmol, 3 equiv) and 2,2,6,6-tetramethyl-1-piperidinyloxy (TEMPO) (0.08 g, 20 mmol %) at room temperature. After stirring for 3 h, the reaction was quenched with a saturated solution of $Na_2S_2O_3$ (10 mL) and was extracted with CH_2Cl_2 (2×25 mL). The combined organic extracts were washed with saturated solutions of $NaHCO_3$ (10 mL), NH_4Cl (10 mL) and brine (2×50 mL), dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified by chromatography on silica gel using 100:0 to 90:10 hexanes/EtOAc to yield the lactones **7a**–**f**.

*4.5.1. 6-(Phenoxymethyl)-5,6-dihydro-2H-pyran-2-one (**7a**).* Isolated as a white solid, 0.33 g (65%); mp 80–82 °C; IR (KBr pellet) ν_{max} 1721 (C=O), 1599, 1495, 1386, 1238, 1087, 1044, 812, 756 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.30–7.15 (m, 2H, 2×Ar–CH), 6.94–6.82 (m, 3H, 3×Ar–CH, 1H, CH=C*H*CH$_2$), 6.04 (ddd, *J*=9.6, 3.9, 2.2 Hz, 1H, C*H*=CHCH$_2$), 4.77–4.68 (m, 1H, CH), 4.15–4.05 (m, 2H, CH_2), 2.65–2.41 (m, 2H, CH=CHC*H*$_2$); ^{13}C NMR (75 MHz, $CDCl_3$) δ 163.4 (C=O), 158.0 (C^q–Ar), 144.8 (CH=*C*H), 129.5 (2×CH–Ar), 121.3 (*C*H=CH), 121.1 (CH–Ar), 114.4 (CH–Ar), 75.5 (CH_2CHO), 68.3 (CH_2O–Ar), 26.1 (CH_2); GC–MS (EI, rel int. %) *m*/*z* 204 ($[M^+]$, 43), 111 (28), 110 (36), 107 (24), 97 (100), 94 (33), 83 (15), 81 (16), 79 (17), 77 (67), 69 (56), 55 (25), 43 (70), 41 (59); HRMS (ESI, MeOH/H_2O) calcd for $C_{12}H_{12}O_3Na$ $[M+Na]^+$, 227.0684; found 227.0672.

*4.5.2. 6-(But-3-enyl)-5,6-dihydro-2H-pyran-2-one (**7b**).* Isolated as a colorless oil, 0.23 g (60%); IR (thin film) ν_{max} 1716 (C=O), 1388, 1065, 1039, 996, 955, 864, 817 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 6.89 (ddd, *J*=9.6, 5.1, 3.9 Hz, 1H, CH=C*H*CH$_2$), 6.03 (dt, *J*=9.6, 1.8 Hz, 1H, C*H*=CHCH$_2$), 5.86–5.73 (m, 1H, C*H*=CH_2), 5.10–4.98 (m, 2H, CH=C*H*$_2$), 4.48–4.39 (m, 1H, CH), 2.36–2.21 (m, 4H, 2×CH_2); ^{13}C NMR (75 MHz, $CDCl_3$) δ 164.5 (C=O), 145.0 (CH=*C*H), 137.1 (*C*H=CH_2), 121.4 (*C*H=CH), 115.6 (CH=C*H*$_2$), 77.1 (CH_2CHO), 33.9 (*C*H$_2$CHO), 29.3 (CH_2), 28.8 (CH_2); GC–MS (EI, rel int. %) *m*/*z* 152 ($[M^+]$, 1), 110 (17), 97 (85), 69 (53), 68 (100), 67 (52), 55 (34), 42 (20), 41 (79), 40 (34); HRMS (ESI, MeOH/H_2O) calcd for $C_9H_{12}O_2Na$ $[M+Na]^+$, 175.0735; found 175.0729.

*4.4.3. 6-Ethyl-5,6-dihydro-2H-pyran-2-one (**7c**).* Isolated as a colorless oil, 0.24 g (75%); IR (thin film) ν_{max} 1714 (C=O), 1251, 1036, 865 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 6.87 (ddd, *J*=9.6, 5.1, 3.3 Hz, 1H, CH=C*H*CH$_2$), 6.02 (dt, *J*=9.6, 1.5 Hz, 1H, C*H*=CHCH$_2$), 4.39–4.30 (m, 1H, CH), 2.34–2.29 (m, 2H, CH=CHC*H*$_2$), 1.85–1.64 (m, 2H, CH_2), 1.00 (t, *J*=7.2 Hz, 3H, CH_3); ^{13}C NMR (75 MHz, $CDCl_3$) δ 164.6 (C=O), 145.1 (CH=*C*H), 121.3 (*C*H=CH), 79.1 (CH_2CHO), 28.8 (CH_2), 27.8 (CH_2), 9.2 (CH_3); GC–MS (EI, rel int. %) *m*/*z* 126 ($[M^+]$, 2), 97 (72), 69 (28), 68 (100), 41 (33), 40 (21); HRMS (ESI, MeOH/H_2O) calcd for $C_7H_{10}O_2Na$ $[M+Na]^+$, 149.0579; found 149.0230.

*4.5.4. 6-(Allyloxymethyl)-5,6-dihydro-2H-pyran-2-one (**7d**).* Isolated as a colorless oil, 0.31 g (75%); IR (thin film) ν_{max} 3524, 3079, 2914, 2867, 1722 (C=O), 1423, 1249, 130, 1051, 848, 663 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 6.89 (ddd, *J*=9.6, 6.0, 2.7 Hz, 1H, CH=C*H*CH$_2$), 5.97 (ddd, *J*=9.6, 2.4, 0.9 Hz, 1H, C*H*=CHCH$_2$), 5.92–5.79 (m, 1H, C*H*=CH_2), 5.28–5.14 (m, 2H, CH=C*H*$_2$), 4.60–4.51 (m, 1H, CH), 4.03 (dt, *J*=5.7, 1.2 Hz, 2H, C*H*$_2$CH=CH_2), 3.62 (d, *J*=4.5 Hz, 2H, CH_2), 2.59–2.31 (m, 1H, CH=CHC*H*$_2$), 2.32–2.43 (m, 1H, CH=CHC*H*$_2$); ^{13}C NMR (75 MHz, $CDCl_3$) δ 163.7 (C=O), 145.0 (CH=*C*H), 134.0 (*C*H=CH_2), 120.9 (*C*H=CH), 117.4 (CH=*C*H$_2$), 76.5 (CHOCH_2OCH$_2$), 72.4 (*C*H$_2$CHCH$_2$), 70.6 (CH_2CHO), 25.9 (CH=CHCH_2); GC–MS (EI, rel int. %) *m*/*z* 169 ([M+1], 1), 154 (46), 126 (68), 97 (34), 81 (13), 69 (74), 55 (30), 43 (90), 41 (86), 40 (37); HRMS (ESI, MeOH/H_2O) calcd for $C_9H_{12}O_3Na$ $[M+Na]^+$, 191.0684; found 191.0680.

*4.4.5. 6-Phenyl-5,6-dihydro-2H-pyran-2-one (**7e**).* Isolated as a colorless oil, 0.22 g (50%); IR (thin film) ν_{max} 1722 (C=O), 1454, 1382, 1246, 1061, 1022, 816, 760, 699 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.45–7.33 (m, 5H, 5×Ar–CH), 6.98 (ddd, *J*=10.0, 5.6, 3.2 Hz, 1H, CH=C*H*CH$_2$), 6.14 (ddd, *J*=10.0, 2.4, 1.2 Hz, 1H, C*H*=CHCH$_2$), 5.44 (dd, *J*=10.8, 5.2 Hz, 1H, CH), 2.66–2.61 (m, 2H, CH_2); ^{13}C NMR (75 MHz, $CDCl_3$) δ 164.1 (C=O), 144.9 (CH=*C*H), 138.4 (C^q–Ar), 128.7 (2×CH–Ar), 128.6 (2×Ar–CH), 126.0 (Ar–CH), 121.7 (*C*H=CH), 79.2 (CH_2CHO), 31.6 (CH_2); GC–MS (EI, rel int. %) *m*/*z* 174 ($[M^+]$, 17), 128 (5), 105 (9), 77 (16), 68 (100), 51 (14); HRMS (ESI, MeOH/H_2O) calcd for $C_{11}H_{10}O_2Na$ $[M+Na]^+$, 197.0579; found 197.0575.

*4.5.6. 5-Phenyl-5,6-dihydro-2H-pyran-2-one (**7f**).* Isolated as a colorless oil, 0.30 g (70%); IR (thin film) ν_{max} 3061, 3029, 2892, 1730

(C=O), 1492, 1398, 1225, 1085, 826, 798, 703, 513 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.40–7.32 (m, 3H, 3×Ar–CH), 7.26–7.21 (m, 2H, 2×Ar–CH), 6.98 (ddd, *J*=9.9, 3.0, 0.9 Hz, 1H, CH=C*H*CH_2), 6.16 (dd, *J*=9.9, 2.1 Hz, 1H, C*H*=$CHCH_2$), 4.55 (ddd, *J*=11.4, 5.7, 1.2 Hz, 1H, CH_2), 4.31 (dd, *J*=11.1, 9.6 Hz, 1H, CH_2), 3.89–3.83 (m, 1H, CH); ^{13}C NMR (75 MHz, $CDCl_3$) δ 163.3 (C=O), 148.9 (CH=*C*H), 137.0 (C^q–Ar), 128.9 (2×Ar–CH), 127.8 (CH–Ar), 127.7 (2×Ar–CH), 121.2 (*C*H=CH), 72.1 (CH_2), 40.1 (CH_2*C*HO); GC–MS (EI, rel int. %) *m*/*z* 174 ([M^+], 14), 144 (100), 116 (66), 115 (81), 57 (45); HRMS (ESI, MeOH/H_2O) calcd for $C_{11}H_{10}O_2Na$ $[M+Na]^+$ 197.0579; found 197.0577.

*4.5.7. (R)-Heptane-1,2-diol (**9**).* To a 50 mL flask containing a suspension of AD-mix α (5.6 g) in *t*-BuOH (20 mL) and water (20 mL) at 0 °C was added 1-heptene (0.4 g, 4 mmol). The mixture was stirred for 24 h at room temperature and then quenched by the addition of a 0.05 M solution of Na_2SO_3 (20 mL). The aqueous layer was extracted with EtOAc. The combined organic phases were washed with 2 M KOH solution (40 mL), brine (2×40 mL), dried over $MgSO_4$, filtered, and concentrated in vacuo. The crude product was purified by chromatography on silica gel using hexanes/EtOAc (50:50) to yield 0.48 g (92%) of the title compound as a colorless oil. $[\alpha]_D^{26}$ −14.1 (*c* 1.00, CH_3OH); IR (thin film) ν_{max} 3354, 2946, 2863, 1461, 1212, 927 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 4.09 (dd, *J*=14.1, 7.2 Hz, 1H, CH_2OH), 3.68 (br s, 1H, CH_2O*H*), 3.65–3.56 (m, 2H, CH_2OH and CHO*H*), 3.40–3.34 (m, 1H, C*H*OH), 1.43–1.34 (m, 2H, CH_2), 1.30–1.21 (m, 6H, 3×CH_2), 0.85 (t, *J*=7.2 Hz, 1H, CH_3); ^{13}C NMR (75 MHz, $CDCl_3$) δ 72.3 (*C*HOH), 66.6 (*C*H_2OH), 32.9 (CH_2), 31.8 (CH_2), 25.2 (CH_2), 22.5 (CH_2), 13.9 (CH_3); GC–MS (EI, rel int. %) *m*/*z* 132 [M^+] (0.5); 115 (3); 101 (43), 83 (100), 61 (21). 55 (98), 41 (69); HRMS (ESI, MeOH/H_2O) calcd for $C_7H_{16}O_2Na$ $[M+Na]^+$, 155.1048; found 155.1056.

4.6. Synthesis of Mosher esters from (9)

To a solution of diol **9** (0.02 g, 0.15 mmol) in CH_2Cl_2 (5 mL) at 0 °C, was added DCC (0.06 g, 0.3 mmol) and DMAP (0.01 g, 0.02 mmol). After 5 min (*R*)-MTPA (0.08 g, 0.35 mmol) was added and the mixture was stirred for 0.5 h at 0 °C. The reaction was allowed to warm to room temperature and stirred for an additional 4 h. After this period, the solvent was removed and the crude product was dissolved in $CDCl_3$ and submitted to a ^{19}F NMR analysis. ^{19}F NMR (282 MHz, $CDCl_3$) δ −71.8 for (*R*)-diol and −72.0 for (*S*)-diol.

*4.6.1. (R)-2-Pentyloxirane (**10**).* In a flask containing a solution of **9** (0.74 g, 5.6 mmol) in CH_2Cl_2 (20 mL) under argon was added Et_3N (1.0 mL, 6.8 mmol). The solution was stirred for 5 min before cooling to 0 °C. Mesyl chloride (0.65 mL, 7 mmol) was added dropwise and the resulting mixture was stirred at room temperature for 3 h. After diluting with Et_2O (10 mL), the precipitate was filtered and washed with Et_2O (3×10 mL). The combined ethereal solution was washed with saturated $NaHCO_3$, dried over $MgSO_4$ and the solvents were removed in vacuo. The crude mesylate was redissolved in MeOH (20 mL) and K_2CO_3 (1.6 g, 11 mmol) was added. The suspension was stirred at room temperature for 3 h, and then quenched with water (10 mL). The organic phase was extracted with CH_2Cl_2 (3×10 mL), and the combined organic phases were washed with water (10 mL) and brine (20 mL) before drying over $MgSO_4$. Removal of the solvent, followed by a careful bulb-to-bulb distillation (80 °C, 80 mmHg) gave 0.33 g (52%) of the title compound as a colorless oil. $[\alpha]_D^{26}$ −8.5 (*c* 1.00, $CHCl_3$); IR (thin film) ν_{max} 2958, 2931, 2860, 1466, 1259, 917 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 2.84–2.81 (m, 1H, OCH_2), 2.66 (t, *J*=3.6 Hz, 1H, OC*H*), 2.38 (dd, *J*=3.6, 2.1 Hz, 1H, OCH_2), 1.49–1.21 (m, 8H, 4×CH_2), 0.84 (t, *J*=6.6 Hz, 3H, CH_3); ^{13}C NMR (75 MHz, $CDCl_3$) δ 53.3 (CHO), 46.8 (CH_2O), 32.3 (CH_2), 31.5 (CH_2), 25.5 (CH_2), 22.4 (CH_2), 13.8 (CH_3); GC–MS (EI, rel int. %) *m*/*z* 114 [M^+] (0,5); 99 (2); 85 (15), 71 (100), 55 (63), 58 (57); 41 (89).

4.7. Synthesis of (*R*,*Z*)-dec-2-ene-1,5-diol (11) from the reaction of 2/(2-Th)BuCu(CN)Li_2 system with (10) followed by deprotection

To a flask equipped with a stirring bar and a rubber septum under argon atmosphere was added anhydrous THF (10 mL) and distilled thiophene (1.05 g, 12.5 mmol). The solution was cooled to −78 °C and *n*-butyllithium in hexanes (1.40 M, 9.0 mL, 12.5 mmol) was added dropwise. The resulting light-yellow solution was warmed to −40 °C and kept for 20 min. After that, this solution was transferred via canula to a suspension of CuCN (0.89 g, 10 mmol) in THF previously cooled to −78 °C. At the end of the addition, the acetone/dry ice bath was exchanged for an ice bath. After 5 min the flask was again placed in a dry ice/acetone bath and *n*-butyllithium in hexanes (1.40 M, 7.10 mL, 10 mmol) was added dropwise. The solution was maintained at this temperature for 15 min. After that, the solution was warmed up to 0 °C and **2** (4.20 g, 10.5 mmol) dissolved in THF (10 mL) was added. After being stirred for 1 h at room temperature, the mixture was cooled to -78 °C and the epoxide **8** (1.14 g, 10 mmol) in THF (10 mL) was added. The reaction mixture was warmed to 0 °C. After 3 h at 0 °C, it was warmed to ambient temperature and stirred for an additional hour. The reaction mixture was then cooled to −78 °C and a solution of saturated aqueous NH_4Cl and aqueous NH_4OH (9:1) was added. The mixture was stirred for 15 min while the temperature of the system was allowed to rise. After that, the mixture was extracted with EtOAc (2×60 mL). The organic layer was washed with brine (2×100 mL). The combined organic layers were dried over $MgSO_4$ and concentrated in vacuo. The residue was then dissolved in THF (5 mL) and TBAF (10 mL, 1 M solution in THF, 10 mmol) was added dropwise. The reaction was monitored by TLC. The reaction was then quenched by the addition of a saturated solution of NH_4Cl (10 mL). The aqueous layer was extracted with EtOAc and the combined organic phases were washed with brine, dried over $MgSO_4$, filtered, and concentrated in vacuo. The crude product was purified by chromatography on silica gel using 50:50 hexanes/EtOAc to yield 1.28 g (75%) of the 1,5-diol, **11** as a yellow oil. $[\alpha]_D^{26}$ −9.7 (*c* 1.00, $CHCl_3$); IR (KBr pellet) ν_{max} 3329 (OH), 2921, 2843, 1661, 1472, 1011, 867, 721 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.90–5.82 (m, 1H, C*H*=CH), 5.67–5.58 (m, 1H, CH=C*H*), 4.17 (dd, *J*=12.0, 7.5 Hz, 1H, CH_2CH=CH), 4.05 (dd, *J*=12.3, 6.6 Hz, 1H, CH_2CH=CH), 3.66–3.58 (m, 1H, CHOH), 2.62 (br s, 2H, 2×OH), 2.28–2.23 (m, 2H, CH=CHCH_2), 1.49–1.40 (m, 2H, CHOHCH_2), 1.35–1.27 (m, 6H, 3×CH_2), 0.89 (t, *J*=6.9 Hz, 3H, CH_3); ^{13}C NMR (75 MHz, $CDCl_3$) δ 131.8 (*C*H=CH), 129.1 (CH=*C*H), 70.0 (CHOH), 57.1 (*C*H_2CH=CH), 36.6 (CH_2), 34.5 (CH_2), 31.8 (CH_2), 25.0 (CH_2), 22.1 (CH_2), 13.6 (CH_3); GC–MS (EI, rel int. %) *m*/*z* 154 (1), 99 (12), 55 (35), 54 (100), 43 (14), 41 (12); HRMS (ESI, MeOH/H_2O) calcd for $C_{10}H_{20}O_2Na$ $[M+Na]^+$, 195.1361; found 195.1364.

4.8. Synthesis of (*R*)-Massoialactone (12) from the reaction of (11) with TEMPO/BAIB

To a stirred solution of the **11** (2.5 mmol, 0.43 g) in CH_2Cl_2 (30 mL) was added bis-acetoxyiodobenzene (BAIB) (2.5 g, 7.7 mmol, 3 equiv) and 2,2,6,6-tetramethyl-1-piperidinyloxy (TEMPO) (0.08 g, 20 mmol %) at room temperature. After stirring for 3 h, the reaction was quenched with a saturated solution of $Na_2S_2O_3$ (10 mL) and was extracted with CH_2Cl_2 (2×25 mL). The combined organic extracts were washed with saturated solutions of $NaHCO_3$ (10 mL), NH_4Cl (10 mL) and brine (2×50 mL), dried over $MgSO_4$, filtered, and concentrated. The residue was purified by chromatography on silica gel using 100:0 to 90:10 hexanes/EtOAc to yield

(**12**)—(*R*)-Massoialactone—as a colorless oil, 0.28 g (70%). $[\alpha]_D^{26}$ −115.6 (*c* 1.00, $CHCl_3$); IR (thin film) ν_{max} 2927, 2849, 1718, 1381, 1257, 1041, 812, 665 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 6.80 (dd, *J*=9.6, 4.4 Hz, 1H, CH=C*H*CH_2), 5.95 (d, *J*=9.6 Hz, 1H, C*H*=$CHCH_2$), 4.38–4.33 (m, 1H, CH), 2.27–2.23 (m, 2H, CH=CHCH_2), 1.74–1.19 (m, 8H, 4×CH_2), 0.83 (t, *J*=6 Hz, 3H, CH_3); ^{13}C NMR (75 MHz, $CDCl_3$) δ 164.2 (C=O), 144.7 (CH=*C*H), 120.9 (*C*H=CH), 77.6 (CH_2*C*HO), 34.3 (CH=*C*HCH_2), 31.5 (CH_2), 28.9 (CH_2), 24.4 (CH_2), 22.0 (CH_2), 13.5 (CH_2); GC–MS (EI, rel int. %) *m*/*z* 169 ([M+1], 2), 154 (41), 137 (23), 126 (62), 109 (42), 97 (37), 95 (20), 55 (28), 43 (89), 42 (29), 41 (83), 40 (34); HRMS (ESI, MeOH/H_2O) calcd for $C_{10}H_{16}O_2Na$ $[M+Na]^+$, 191.1048; found 191.1045.

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Supplementary data

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.tet.2011.02.029. These data include MOL files and InChIKeys of the most important compounds described in this article.

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