Diversely Substituted Sugar-Linked α,β-Unsaturated γ-Lactones from Sugar-Derived Baylis−Hillman Adducts via a RCM

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A versatile protocol for the production of sugar-linked α,β-unsaturated γ-lactones with stereochemical and functional group diversity is described starting from sugar-derived Baylis−Hillman adducts via ring-closing metathesis.

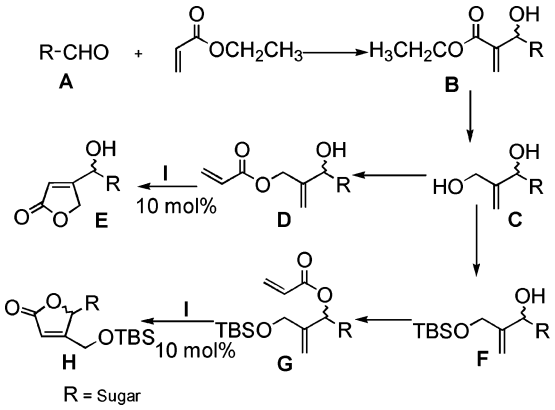
Introduction

The Baylis−Hillman reaction is one of the most well-studied C−C bond formations.[1] It is also well documented in the literature that Baylis−Hillman adducts serve as advanced key intermediates in the synthesis of many biologically active natural products.[2] Likewise the transition metal-catalyzed ring-closing metathesis has been the subject of much attention in the recent years,[3] and the development of ruthenium carbene complexes by Grubbs and co-workers[4] is particularly notable because of the functional group tolerance, operational simplicity, and ready availability of the catalyst. In the recent years, we have been involved in expanding the horizon of the asymmetric Baylis−Hillman[5] reaction and also in elaborating the ensuing adducts in the synthesis of bioactive natural products.[6] α,β-Unsaturated γ-lactone scaffolds rank among the most ubiquitous structural motifs found in naturally occurring organic molecules.[7] Many of these compounds exhibit a variety of properties such as antifungal, insecticidal, antibacterial, phytotoxic, or anti-inflammatory activities, and some are antibiotics, potential anticancer agents, and cyclooxygenase or phospholipase A2 inhibitors.[8] Because of the wide prevalence of α,β-unsaturated γ-lactone[9] skeletons in natural products, the regio- and stereoselective synthesis of this compound has been a focus of intensive efforts to help speed up the drug discovery process. Furthermore, a combination of the Baylis−Hillman reaction, which produces an olefin en route, and ring-closing metathesis (RCM) protocol is envisioned to be a means of ready access to α,β-unsaturated γ-lactones as products. Toward this endeavor, we describe our results herein for the conversion of sugar-derived Baylis−Hillman adducts via a RCM into diversely substituted sugar-linked α,β-unsaturated γ-lactones.[6]

Consequently, to introduce diverse stereochemical and functional group elements into the end products, we have chosen sugar-derived aldehydes, such as 1,2-*O*-isopropylidene-3-*O*-methyl-α-D-*xylo*-pentodialdo-1,4-furanose[10] (**1**), 2,3-*O*-isopropylidene-1-*O*-methyl-α-D-*xlyo*-pentodialdo-1,4-furanose[11] (**2**), and 2,3-*O*-isopropylidene-1-*O*-methyl-α-D-*ribo*-pentodialdo-1,4-furanose **(3),** as chiral electrophiles in Baylis−Hillman reactions to derive chiral adducts as products which could further be extrapolated to diverse α,β-unsaturated γ-lactones via RCM of the ensuing acrylates in solution phase. These end products, in addition to retaining the stereochemical integrity of the starting materials, possess newer structural motifs in the form of butenolides.

Results and Discussion

To delineate this approach, particularly in regard to library construction, we conceived a two-pronged strategy (eq 1).



(1)

First the sugar-derived Baylis−Hillman adduct (**B**) could be reduced to the corresponding diol (**C**) and then acryloylated to produce the monoacryloylated derivative (**D**), which upon RCM reaction would give a sugar-linked 4-substituted-γ-lactone (**E**). Additionally, the diol (**C**), upon selective protection with TBSCl, would yield **F**, which upon acrylolation and RCM reaction gives a sugar-linked 4,5-disubstituted-γ-lactone (**H**).

Accordingly, the reaction of aldehyde and ethyl acrylate in the presence of DABCO in 1,4-dioxane/water (1:1) at room temperature for 24 h yielded the adduct **1a** (Scheme 1) as a mixture of inseparable diastereomers (36% de). Aldehydes **2** and **3** were reacted, in a similar manner, with ethyl acrylate in the presence of DABCO in DMSO

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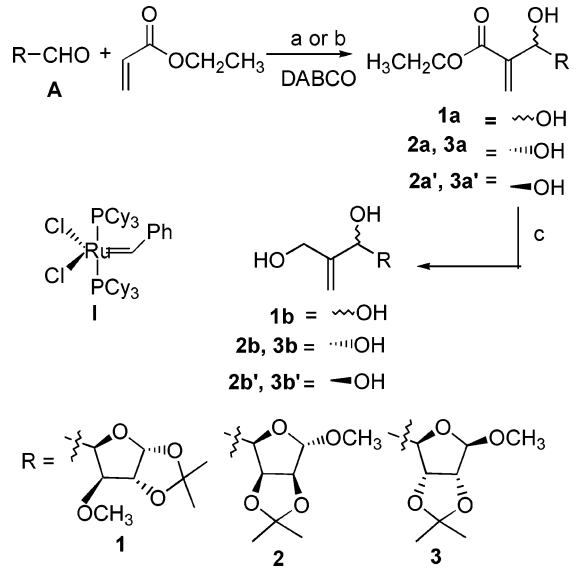
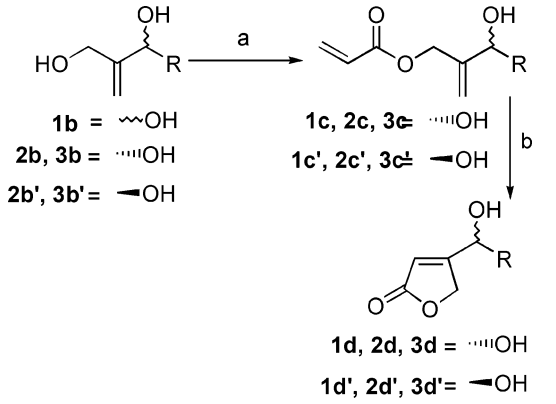
Scheme 1[a]



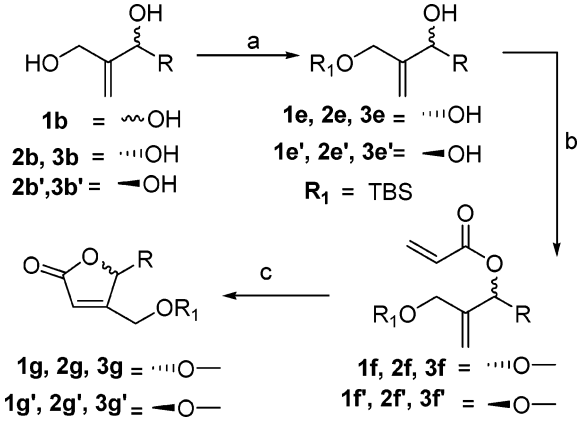
[a] (a) 1,4-Dioxane/H_2O (1:1), room temp, 24 h; (b) DMSO, room temp, 24 h; (c) LAH, $AlCl_3$, ether, 0 °C, 2 h.

Scheme 2[a]



[a] (a) Acryloyl chloride, *N*-ethyldiisopropylamine, CH_2Cl_2, 0 °C to room temp,10 h; (b) Grubb's catalyst (**I**, 10 mol %), CH_2Cl_2, 36 h.

Scheme 3[a]



[a] (a) TBSCl, imidazole, CH_2Cl_2, room temp, 10 h; (b) acryloyl chloride, *N*-ethyldiisopropylamine, CH_2Cl_2, 0 °C to room temp, 10 h; (c) Grubb's catalyst (**I**, 10 mol %), CH_2Cl_2, 48 h.

medium at room temperature for 24 h to give adducts **2a**, **3a,** **2a′**, and **3a′**, respectively, in good yields as separable diastereomers. The absolute stereochemistry of major isomer in **1a** was assigned as S on the basis of literature evidence.[12] The S stereoselectivity can be explained by the favorable attack of the carbanion from the *Si* face of the sugar-derived aldehyde leading to the S isomer as the major product at the newly created center, according to the Felkin−Anh model, by a nonchelation protocol. Similarly, the stereochemistry of the major isomers in **2a** and **3a** is expected to be the same because they are derived from D-sugars.

Table 1. Series of Sugar-Derived Lactones

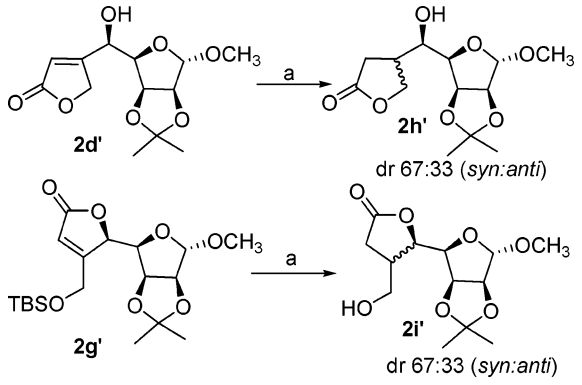
Entry	Product	Time(h)	Yield[a](%)
1	**1d**	36	68
2	**1d'**	36	68
3	**1g**	48	62
4	**1g'**	48	62
5	**2d**	36	67
6	**2d'**	36	65
7	**2g**	48	62
8	**2g'**	48	61
9	**3d**	36	66
10	**3d'**	36	64
11	**3g**	48	60
12	**3g'**	48	61

[a] Isolated yields for the final RCM step.

As depicted in Schemes 2 and 3, the ester functionality in adducts **1a**, **2a**, **3a**, **2a′**, and **3a′** was reduced with LAH/$AlCl_3$[13] to afford diols **1b**, **2b**, **3b**, **2b′**, and **3b′**, which upon acryloylation (acryloyl chloride/*N*-ethyldiisopropyl amine/CH_2Cl_2/room temperature) yielded monoacrylate esters **1c**, **2c**, **3c**, **1c′**, **2c′**, and **3c′**, where **1c** and **1c′** were separated by column chromatography. Monoacrylate esters **1c**, **2c**, **3c**, **1c′**, **2c′**, and **3c′** were subjected to RCM with Grubb's catalyst (standard ruthenium complex **I**, 10 mol %, CH_2Cl_2, reflux) to give 4-substituted-α,β-unsaturated-γ-lactones **1d**, **2d**, **3d**, **1d′**, **2d′**, and **3d′** in moderate yields.

Subsequently, diols **1b**, **2b**, **3b**, **2b′**, and **3b′** were protected as TBDMS ethers by treatment with TBDMSCl and imidazole in dry CH_2Cl_2 at room temperature for 10 h to yield **1e**, **2e**, **3e**, **1e′**, **2e′**, and **3e′**. The reaction of **1e**, **2e**, **3e**, **1e′**, **2e′**, and **3e′** with acryloyl chloride and *N*-ethyldiisopropyl-

Scheme 4[a]



[a] (a) H_2, Pd/C, MeOH, 6 h.

amine in CH_2Cl_2 provided the acrylate esters **1f**, **2f**, **3f**, **1f′**, **2f′**, and **3f′**. Finally, ring-closing metathesis on **1f**, **2f**, **3f**, **1f′**, **2f′**, and **3f′** using Grubb's catalyst (standard ruthenium complex **I**, 10 mol %) in refluxing CH_2Cl_2 for 48 h gave the 4,5-disubstituted α,β-unsaturated γ-lactones **1g**, **2g**, **3g**, **1g′**, **2g′**, and **3g′** in moderate yields. In total, a small library of 12 different lactones with stereochemical and regiochemical diversity was prepared starting from 3 different sugars; their yields and reaction times are shown in Table 1.

Sugar is used as a template for the creation of a new chiral center on the butyrolactone skeleton. Additionally, the hydroxyl functional group at C(5) can act as the diversity point both stereochemically and functionally, and the chirality can be extended through the butyrolactone moiety by induction.[14] To demonstrate this possibility, **2d′** and **2g′** (Scheme 4) were subjected to hydrogenation in presence of Pd−C at room temperature to give **2h′** and **2i′** in quantitative yields as an inseparable mixture in a 6.7:3.3 ratio. It is interesting to note that both **2h′** and **2i′** are indeed stereochemically diverse sugar-linked butanolides possessing chiral tertiary stereocenters.

Conclusion

Diversity-oriented synthesis (DOS) is a preferred technique in the development of focused libraries. In conclusion, we have prepared a series of structurally diverse α,β-unsaturated γ-lactones from sugar-derived Baylis−Hillman adducts via a RCM protocol. These lactones not only serve as useful intermediates in the synthesis of many bioactive natural products but are also suitable for biological screening because of their natural productlike profiles.

Experimental Section

Solvents were dried over standard drying agents and freshly distilled prior to use. ^{1}H NMR (200, 300, and 400 MHz) and ^{13}C NMR (50 and 75 MHz) spectra were measured with a Varian Gemini FT-200 MHz spectrometer, Bruker Avance 300 MHz, and Unity 400 MHz with tetramethylsilane as an internal standard for solutions in deuteriochloroform. *J* values are given in hertz. IR spectra were recorded on a Perkin-Elmer IR-683 spectrophotometer with NaCl optics. Optical rotations were measured with JASCO DIP 300 digital polarimeter at 25 °C. Mass spectra were recorded on CEC-21-11013 or Fannigan Mat 1210 double-focusing mass spectrometers operating at a direct inlet system. Organic solutions were dried over anhydrous Na_2SO_4 and concentrated below 40 °C in vacuo.

Compound 1a. 1,2-*O*-Isopropylidene-3-*O*-methyl-α-D-*xylo*-pentodialdo-1,4-furanose (**1**; 4.0 g, 19.8 mmol) in dioxane/water (1:1, 30 mL) was treated with ethyl acrylate (4.3 mL, 39.6 mmol) in presence of DABCO (2.2 g, 19.8 mmol) at room temperature for 24 h. Then the reaction mixture was diluted with water (2 × 15 mL) and extracted with ethyl acetate (3 × 40 mL). The combined organic layers were washed with brine (25 mL), dried (Na_2SO_4), and concentrated under reduced pressure to get a residue, which was purified by chromatography (silica gel 60−120 mesh, *n*-hexane/EtOAc, 8.5:1.5−8:2) to yield the adduct (4.42 g, 74%) as a colorless syrup with 36% de as determined by chiral HPLC analysis. ^{1}H NMR (200 MHz, $CDCl_3$, TMS): δ 6.37 (s, 0.32H, olefinic), 6.33 (s, 0.68H, olefinic), 6.08 (s, 0.32H, olefinic), 5.92 (s, 0.68H, olefinic), 5.83 (d, 1H, J = 3.9 Hz, H-1), 4.81 (br. s, 0.32H, H-5), 4.62 (br. s, 0.68H, H-5) 4.54 (d, 1H, J = 3.9 Hz, H-2), 4.32−4.18 (m, 3H, H-4, CH_2), 3.82 (br. s, 1H, H-3), 3.45 (s, 3H, OMe), 1.42 (s, 3H, CH_3), 1.38−1.24 (m, 6H, 2 x CH_3). IR (neat): ν 3410, 1748, 1680 cm^{-1}. ES-MS: *m*/*z* 303 (M^+ + 1). Anal. Calcd for $C_{14}H_{22}O_7$: C, 55.62; H, 7.33. Found: C, 55.67; H, 7.29.

Compound 1b. A solution of $AlCl_3$ (0.440 g, 3.3 mmol) in dry ether (5 mL) was added to a cooled solution of $LiAlH_4$ (0.367 g, 9.93 mmol) in dry ether (5 mL), and the mixture was stirred for 15 min. Then a solution of **1a** (2.0 g, 6.62 mmol) in dry ether (10 mL) was added, and the mixture was stirred at 0 °C for 2 h. After the completion of reaction, it was quenched with a saturated Na_2SO_4 solution at 0 °C and filtered through a pad of celite eluting with ethyl acetate (50 mL). The filtrate was concentrated under reduced pressure to obtain a residue, which was purified by chromatography (silica gel 60−120 mesh, *n*-hexane/EtOAc, 6:4) to yield diol **1b** (1.17 g, 68%) as a colorless syrup. $[\alpha]_D = -45.5$ (*c* 0.8, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$, TMS): δ 5.85 (d, 1H, J = 3.9 Hz, H-1), 5.24 (d, 2H, J = 6.3 Hz, olefinic), 4.56 (d, 1H, J = 3.9 Hz, H-2), 4.46 (d, 1H, J = 7.8 Hz, H-5), 4.25 (d, 1H, J = 3.1 Hz, H-4), 4.17 (dd, 2H, J = 3.1, 8.6 Hz, CH_2), 3.85 (d, 1H, J = 3.1 Hz, H-3), 3.47 (s, 3H, OMe), 3.04 (br. s, 1H, OH), 1.51 (s, 3H, CH_3), 1.36 (s, 3H, CH_3). IR (neat): ν 3415, 2946, 1665, 1460, 1384, 1094, 1030, 870. ES-MS: *m*/*z* 261 (M^+ + 1). Anal. Calcd for $C_{12}H_{20}O_6$: C, 55.37; H, 7.74. Found: C, 55.30; H, 7.68.

Compounds 1c and 1c′. Acryloylchloride (0.13 mL, 1.53 mmol) was added dropwise at 0 °C to a stirred solution of **1b** (0.4 g, 1.53 mmol) and *N*-ethyldiisopropylamine (0.53 mL, 3.07 mmol) in CH_2Cl_2 (10 mL), and the mixture was stirred at room temperature for 10 h. The reaction mixture was treated with water (1 × 15 mL) and extracted into CH_2Cl_2 (2 × 15 mL). The combined organic layers were washed with brine (1 × 15 mL), dried (Na_2SO_4), and evaporated under reduced pressure. The residue was purified by column chromatograpy (silica gel 100−200 mesh, *n*-hexane/EtOAc 8.8:1.2) to afford acrylates **1c** (0.246 g, 50.9%) and **1c′** (0.116 g, 24%) as light yellow syrups. Compound **1c**. $[\alpha]_D = -7.36$ (*c* 0.1, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ 6.43 (dd, 1H, J = 1.51, 17.37 Hz,

olefinic*)*, 6.14 (dd, 1H, *J* = 10.57, 17.37 Hz, olefinic*)*, 5.9−5.82 (m, 2H, H-1, olefinic), 5.38 (s, 1H, olefinic), 5.30 (s, 1H, olefinic), 4.82−4.70 (m, 2H, OCH_2), 4.50 (m, 2H, H-2, H-5), 4.2 (dd, 1H, *J* = 3.77, 7.55 Hz, H-4), 3.66 (d, 1H, *J* = 3.77 Hz, H-3), 3.38 (s, 3H, OMe), 1.48 (s, 3H, CH_3), 1.30 (s, 3H, CH_3). IR (neat): *ν* 3441, 2986, 2942, 1724, 1640, 1410, 1380, 1094, 870. ES-MS: *m*/*z* 315 ($M^+ + 1$). Anal. Calcd for $C_{15}H_{22}O_7$: C, 57.32; H, 7.05. Found: C, 57.26; H, 6.97. Compound **1c′**. $[\alpha]_D = -35.78$ (*c* 0.4, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): *δ* 6.43 (dd, 1H, *J* = 1.51, 17.37, olefinic*)*, 6.13 (dd, 1H, *J* = 10.57, 17.37 Hz, olefinic*)*, 5.86 (m, 2H, H-1, olefinic), 5.4 (s, 1H, olefinic), 5.32 (s, 1H, olefinic), 4.78 (s, 2H, OCH_2), 4.52 (d, 1H, *J* = 3.77 Hz, H-2), 4.44 (d, 1H, *J* = 6.79 Hz, H-5), 4.12 (dd, 1H, *J* = 3.02, 7.55 Hz, H-4), 3.85 (d, 1H, *J* = 3.02 Hz, H-3), 3.48 (s, 3H, OMe), 2.7 (d, 1H, *J* = 5.28 Hz, −OH), 1.48 (s, 3H, CH_3), 1.30 (s, 3H, CH_3). IR (neat): *ν* 3430, 2985, 2945, 1720, 1642, 1412, 1385, 1095, 865. ES-MS: *m*/*z* 315 ($M^+ + 1$). Anal. Calcd for $C_{15}H_{22}O_7$: C, 57.32; H, 7.05. Found: C, 57.27; H, 6.98.

Compound 1d. A solution of **1c (**0.1 g, 0.31 mmol) and first generation Grubbs' catalyst (0.026 g, 0.032 mmol) in dry CH_2Cl_2 (80 mL) was stirred at reflux for 36 h. Then the solvent was removed under reduced pressure, and the residue was purified by chromatography (silica gel 60−120 mesh, *n*-hexane/EtOAc 7:3) to afford **1d** (0.062 g, 68%) as a dark syrup. $[\alpha]_D = -18.06$ (*c* 0.25, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$, TMS): *δ* 5.94 (s, 1H, olefinic), 5.92 (d, 1H, *J* = 4.0 Hz, H-1), 5.03−4.9 (m, 3H, OCH_2, H-5), 4.58 (d, 1H, *J* = 4.0 Hz, H-2), 4.16 (d, 1H, *J* = 4.0 Hz, H-4), 3.82 (d, 1H, *J* = 4.0 Hz, H-3), 3.48 (s, 3H, OMe), 1.45 (s, 3H, CH_3), 1.3 (s, 3H, CH_3). IR (neat): *ν* 3435, 2942, 1754, 1642, 1378, 1216, 1094, 864. ^{13}C NMR (75 MHz, $CDCl_3$, TMS): *δ* 172.0, 167.2, 116.2, 110.2, 90.1, 85.4, 80.4, 71.4, 69.7, 56.2, 51.2, 26.2, 25.1. FAB-MS: *m*/*z* 287 ($M^+ + 1$). Anal. Calcd for $C_{13}H_{18}O_7$: C, 54.54; H, 6.34. Found: C, 54.50; H, 6.29.

Compound 1d′. A solution of **1c′** (0.1 g, 0.31 mmol) and first generation Grubbs' catalyst (0.026 g, 0.032 mmol) in dry CH_2Cl_2 (80 mL) was stirred at reflux for 36 h. The reaction mixture was worked up and purified as described for **1d** to afford **1d′** (0.062 g, 68%) as a dark syrup. $[\alpha]_D = -65.96$ (*c* 0.1, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$, TMS): *δ* 6.12 (s, 1H, olefinic), 5.88 (d, 1H, *J* = 3.71 Hz, H-1), 5.06−4.8 (m, 2H, OCH_2), 4.73 (d, 1H, *J* = 7.4 Hz, H-5), 4.55 (d, 1H, *J* = 3.71 Hz, H-2), 4.14 (dd, 1H, *J* = 2.97, 8.17, H-4), 3.9 (d, 1H, *J* = 2.97, H-3), 3.48 (s, 3H, OMe), 1.45 (s, 3H, CH_3), 1.3(s, 3H, CH_3). IR (neat): *ν* 3432, 2942, 1754, 1643, 1382, 1212, 1096, 862. ^{13}C NMR (75 MHz, $CDCl_3$, TMS): *δ* 172.2, 167.2, 116.9, 110.4, 90.5, 85.2, 80.5, 71.6, 69.6, 56.4, 51.3, 26.3, 24.7. ES-MS: *m*/*z* 287 ($M^+ + 1$). Anal. Calcd for $C_{13}H_{18}O_7$: C, 54.54; H, 6.34. Found: C, 54.48; H, 6.26.

Compound 1e and 1e′. TBDMSCl (0.347 g, 2.3 mmol) was added to a solution of **1b** (0.6 g, 2.3 mmol) and imidazole (0.314 g, 4.6 mmol) in dry CH_2Cl_2 (15 mL), and the mixture was stirred for 10 h. The reaction mixture was treated with water (1 × 20 mL) and extracted into CH_2Cl_2 (2 × 20 mL). The combined organic layers were washed with brine (1 × 20 mL), dried (Na_2SO_4), and evaporated under reduced pressure. The residue was purified by column chromatograpy (silica gel 100−200 mesh, *n*-hexane/EtOAc 9:1) to afford **1e** (0.492 g, 57%) and **1e′** (0.232 g, 26.9%) as a colorless syrups. Compound **1e**. $[\alpha]_D = -55.04$ (*c* 0.9, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$, TMS): *δ* 5.88 (d, 1H, *J* = 3.90 Hz, H-1), 5.22 (s, 1H, olefinic), 5.18 (s,1H, olefinic), 4.50 (d, 1H, *J* = 3.90 Hz, H-2), 4.42−4.32 (m, 2H, H-5, OCH_2), 4.25−4.1 (m, 2H, OCH_2, H-4), 3.83 (d, 1H, *J* = 3.12 Hz, H-3), 3.48 (s, 3H, OMe), 1.48 (s, 3H, CH_3), 1.3 (s, 3H, CH_3), 0.92 (s, 9H, 3 × CH_3), 0.08 (s, 6H, 2 × CH_3). IR (neat): *ν* 3450, 2938, 2865, 1662, 1469, 1382, 1260, 1095, 846. ES-MS: *m*/*z* 375 ($M^+ + 1$). Anal. Calcd for $C_{18}H_{34}O_6Si$: C, 57.72; H, 9.15. Found: C, 57.67; H, 9.10. Compound **1e′**. $[\alpha]_D = -90.61$ (*c* 2.1, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$, TMS): *δ* 5.84 (d, 1H, *J* = 3.72 Hz, H-1), 5.22 (s, 1H, olefinic), 5.18 (s, 1H, olefinic), 4.51 (d, 1H, *J* = 3.72 Hz), 4.4−4.26 (m, 2H, -OCH_2, H-5), 4.2−4.05 (m, 2H, OCH_2, H-4), 3.83 (d, 1H, *J* = 2.97 Hz, H-3), 3.48 (s, 3H, OMe), 1.48 (s, 3H, CH_3), 1.3 (s,3H, CH_3), 0.92 (s, 9H, 3 × CH_3), 0.08 (s, 6H). IR (neat): *ν* 3438, 2940, 2865, 1670, 1470, 1385, 1265, 1095, 850. ES-MS: *m*/*z* 375 ($M^+ + 1$). Anal. Calcd for $C_{18}H_{34}O_6Si$: C, 57.72; H, 9.15; found: C, 57.71; H, 9.13.

Compound 1f. Acryloylchloride (0.04 mL, 0.53 mmol) was added dropwise at 0 °C to a stirred solution of **1e** (0.2 g, 0.53 mmol) and *N*-ethyldiisopropylamine (0.18 mL, 1.06 mmol) in CH_2Cl_2 (2 mL), and the mixture was stirred at room temperature for 10 h. The reaction mixture was treated with water (1 × 10 mL) and extracted into CH_2Cl_2 (2 × 10 mL). The combined organic layers were washed with brine (1 × 10 mL), dried (Na_2SO_4), and evaporated under reduced pressure. The residue was purified by column chromatograpy (silica gel 60−120 mesh, *n*-hexane/EtOAc 9.3:0.7) to afford acrylate **1f** (0.2 g, 86%) as a light yellow syrup. $[\alpha]_D = -16.76$ (*c* 0.8, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): *δ* 6.4 (dd, 1H, *J* = 1.51, 17.37 Hz, olefinic), 6.15 (dd, 1H, *J* = 9.8, 17.37 Hz, olefinic), 5.88 (d, 1H, *J* = 3.77, H-1), 5.8 (dd, 1H, *J* = 1.51, 9.8 Hz, olefinic), 5.43 (d, 1H, *J* = 9.06 Hz, H-5), 5.35 (s, 1H, olefinic), 5.28 (s, 1H, olefinic), 4.5 (d, 1H, *J* = 3.77, H-2), 4.42 (dd, 1H, *J* = 3.77, 9.06 Hz, H-4), 4.28 (d, 1H, *J* = 14.35, Hz, OCH_2), 4.07 (d, 1H, *J* = 14.35, Hz, OCH_2), 3.62 (d, 1H, *J* = 3.77 Hz, H-3), 3.32 (s, 3H, OMe), 1.5 (s, 3H, CH_3), 1.3 (s, 3H, CH_3), 0.9 (s, 9H, 3 × CH_3), 0.05 (s, 6H, 2 × CH_3). IR (neat): *ν* 2936, 2859, 1732, 1633, 1469, 1380, 842. ES-MS: *m*/*z* 429 ($M^+ + 1$). Anal. Calcd for $C_{21}H_{36}O_7Si$: C, 58.85; H, 8.47. Found: C, 58.79; H, 8.40.

Compound 1f′. Acryloylchloride (0.04 mL, 0.53 mmol) was added dropwise at 0 °C to a stirred solution of **1e′** (0.2 g, 0.53 mmol) and *N*-ethyldiisopropylamine (0.18 mL, 1.06 mmol) in CH_2Cl_2 (2 mL), and the mixture was stirred at room temperature for 10 h. The reaction mixture was worked up and purified as described for **1f** to yield **1f′** (0.196 g, 86%) as a light yellow syrup. $[\alpha]_D = -51.29$ (*c* 0.85, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): *δ* 6.4 (dd, 1H, *J* = 1.51, 17.18 Hz, olefinic), 6.15 (dd, 1H, *J* = 10.38, 17.18 Hz, olefinic), 5.83 (m, 2H, H-1, olefinic), 5.4−5.3 (m, 2H, olefinic, H-5), 5.22 (s, 1H, olefinic), 4.49 (d, 1H, *J* = 3.77

Hz, H-2), 4.3−4.2 (m, 3H, OCH_2, H-4), 3.65 (d, 1H, J = 3.02 Hz, H-3), 3.32 (s, 3H, OMe), 1.48 (s, 3H, CH_3), 1.3 (s, 3H, CH_3), 0.9 (s, 9H, 3 × CH_3), 0.05 (s, 6H, 2 × CH_3). IR (neat): ν 2940, 2865, 1724, 1640, 1470, 1378, 845. ES-MS: m/z 429 ($M^+ + 1$). Anal. Calcd for $C_{21}H_{36}O_7Si$: C, 58.85; H, 8.47. Found: C, 58.84; H, 8.45.

Compound 1g. A solution of **1f** (0.1 g, 0.233 mmol) and first generation Grubbs' catalyst (0.019 g, 0.023 mmol) in dry CH_2Cl_2 (80 mL) was stirred at reflux for 48 h. Then the solvent was removed under reduced pressure, and the residue was purified by chromatography (silica gel 60−120 mesh, *n*-hexane/EtOAc 9:1) to give **1g** (0.058 g, 62%) as a dark syrup. $[\alpha]_D = -18.45$ (c 0.15, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ 5.98 (br. s, 1H, olefinic), 5.8 (d, 1H, J = 3.77 Hz, H-1), 5.13 (d, 1H, J = 4.53 Hz, H-5), 4.6−4.5 (m, 3H, H-2, H-4, OCH_2), 4.4 (dd, 1H, J = 1.51, 17.37 Hz, OCH_2), 3.88 (d, 1H, J = 4.53 Hz, H-3), 3.32 (s, 3H, OMe), 1.4 (s, 3H, CH_3), 1.3 (s, 3H, CH_3), 0.9 (s, 9H, 3 × CH_3), 0.06 (s, 6H, 2 × CH_3). IR (neat): ν 2942, 2862, 1768, 1652, 1375, 1264, 1110, 855. ^{13}C NMR (75 MHz, $CDCl_3$, TMS): δ 174, 171.9, 115.5, 113, 105.3, 83.9, 81.2, 80.6, 77.4, 60.0, 58.2, 26.4, 25.9, 25.5(3C), 17.9, −6(2C). FAB-MS: m/z 401 ($M^+ + 1$). Anal. Calcd for $C_{19}H_{32}O_7$: C, 56.97; H, 8.05. Found: C, 56.96; H, 8.04.

Compound 1g′. A solution of **1f′** (0.1 g, 0.233 mmol) and first generation Grubbs' catalyst (0.019 g, 0.023 mmol) in dry CH_2Cl_2 (80 mL) was stirred at reflux for 48 h. The reaction mixture was worked up and purified as described for **1g** to give **1g′** (0.058 g, 62%) as a dark syrup. $[\alpha]_D = -6.6$ (c 0.3, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ 6.05 (Br.s, 1H, olefinic), 5.85 (d, 1H, J = 3.77 Hz, H-1), 5.12 (d, 1H, J = 9.06 Hz, H-5), 4.74 (dd, 1H, J = 2.26, 18.88 Hz, OCH_2), 4.52 (d, 1H, J = 3.77 Hz, H-2), 4.37 (dd, 1H, J = 2.26, 18.88 Hz, OCH_2), 3.88 (d, 1H, J = 3.02 Hz, H-3), 3.82 (dd, 1H, J = 3.02, 9.06 Hz, H-4), 3.35 (s, 3H, OMe), 1.4 (s, 3H, CH_3), 1.3 (s, 3H, CH_3), 0.9 (s, 9H, 3 × CH_3), 0.06 (s, 6H, 2 × CH_3). IR (neat): ν 2942, 2858, 1768, 1652, 1382, 1254, 1104, 852. ^{13}C NMR (75 MHz, $CDCl_3$, TMS): δ 173.8, 171.7, 115.4, 112.9, 105.8, 83.6, 81.5, 80.4, 77.9, 60.4, 58.4, 26.8, 26.1, 25.6 (3C), 18.1, −5.3 (2C). ES-MS: m/z 401 ($M^+ + 1$). Anal. Calcd for $C_{19}H_{32}O_7$: C, 56.97; H, 8.05. Found: C, 56.92; H, 8.02.

Compound 2a and 2a′. Compounds **2a** (51.4%) and **2a′** (14.6%) were obtained as colorless syrups. Compound **2a**. $[\alpha]_D = +171.47$ (c 3.8, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ 6.44 (s, 1H, olefinic), 6.05 (s, 1H, olefinic), 4.96 (s, 1H, H-1), 4.68 (d, 1H, J = 6.04 Hz, H-3), 4.54 (br. s, 1H, H-5), 4.50 (d, 1H, J = 6.04 Hz, H-2), 4.22 (q, 2H, J = 6.93 Hz, OCH_2), 4.08 (d, 1H, J = 6.04 Hz, H-4), 3.49 (s, 3H, OMe), 1.51 (s, 3H, CH_3), 1.42 (s, 3H, CH_3), 1.3 (t, 3H, J = 6.93 Hz, CH_3). IR (neat): ν 3421, 2986, 2940, 1714, 1631, 1450, 1377, 1320, 1159, 1091, 960. ES-MS: m/z 303 (M^++1). Anal. Calcd for $C_{14}H_{22}O_7$: C, 55.62; H, 7.33. Found: C, 55.57; H, 7.31. Compound **2a′**. $[\alpha]_D = +141.20$ (c 1.65, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ 6.32 (s, 1H, olefinic), 5.95 (s, 1H, olefinic), 4.84 (s, 1H, H-1), 4.8−4.7 (m, 2H, H-3, H-5), 4.5 (d, 1H, J = 6.04 Hz, H-2), 4.24 (q, 2H, J = 6.04 Hz, OCH_2), 4.08 (dd, 1H, J = 3.8, 7.6 Hz, H-4), 3.28 (s, 3H, OMe), 1.51 (s, 3H, CH_3), 1.42 (s, 3H, CH_3), 1.3 (t, 3H, J = 6.04 Hz, CH_3). IR (neat): ν 3418, 2982, 2936, 1713, 1640, 1450, 1377, 1318, 1088, 958. ES-MS: m/z 303 ($M^+ + 1$). Anal. Calcd for $C_{14}H_{22}O_7$: C, 55.62; H, 7.33. Found: C, 55.60; H, 7.30.

Compound 2b. Compound **2b** was isolated in a 66% yield as a colorless syrup. $[\alpha]_D = +170.78$ (c 0.65, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ 5.28 (s, 1H, olefinic), 5.24 (s, 1H, olefinic), 4.96 (s, 1H, H-1), 4.80 (d, 1H, J = 6.04 Hz, H-3), 4.54 (d, 1H, J = 6.04 Hz, H-2), 4.49 (br. s, 1H, H-5), 4.32 (br. s, 1H, H-4) 4.2 (br. s, 2H, OCH_2), 3.92 (s, 1H, OH) 3.45 (s, 3H, OMe), 1.45 (s, 3H, CH_3), 1.29 (s, 3H, CH_3). IR (neat): ν 3415, 2946, 1675, 1455, 1382, 1090, 1028, 870. ES-MS: m/z 261 ($M^+ + 1$). Anal. Calcd for $C_{12}H_{20}O_6$: C, 55.37; H, 7.74. Found: C, 55.32; H, 7.69.

Compound 2b′. Compound **2b′** was isolated in a 66% yield as a white solid. mp: 112 °C. $[\alpha]_D = +144.45$ (c 0.8, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ 5.30 (s, 1H, olefinic), 5.25 (s, 1H, olefinic), 4.9 (s, 1H, H-1), 4.84 (dd, 1H, J = 3.77, 6.04 Hz, H-3), 4.54 (d, 1H, J = 6.04 Hz, H-2), 4.50 (d, 1H, J = 9.82 Hz, H-5), 4.22−4.18 (m, 2H, OCH_2), 3.98 (dd, 1H, J = 3.77, 8.30 Hz, H-4), 3.32 (s, 3H, OMe), 1.5 (s, 3H, CH_3), 1.35 (s, 3H, CH_3). IR (KBr): ν 3416, 2940, 1670, 1460, 1385, 1085, 1035, 868. ES-MS: m/z 261 ($M^+ + 1$). Anal. Calcd for $C_{12}H_{20}O_6$: C, 55.37; H, 7.74. Found: C, 55.34; H, 7.72.

Compound 2c. Compound **2c** was isolated in a 75% yield as a colorless syrup. $[\alpha]_D = +125.30$ (c 0.3, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ 6.43 (dd, 1H, J = 1.51, 17.37 Hz, olefinic), 6.15 (dd, 1H, J = 10.57, 17.37 Hz, olefinic), 5.85 (dd, 1H, J = 1.51, 10.57 Hz, olefinic), 5.49 (s, 1H, olefinic), 5.40 (s, 1H, olefinic), 4.96 (s, 1H, H-1), 4.76 (d, 1H, J = 6.04 Hz, H-3), 4.70 (d, 2H, J = 4.53 Hz, OCH_2), 4.54 (d, 1H, J = 6.04 Hz H-2), 4.46 (br. s, 1H, H-5), 4.25 (br. s, 1H, H-4), 3.48 (s, 3H, OMe), 1.45 (s, 3H, CH_3), 1.25 (s, 3H, CH_3). IR (neat): ν 3440, 2989, 2940, 1725, 1638, 1408, 1384, 1094, 869. ES-MS: m/z 315 ($M^+ + 1$). Anal. Calcd for $C_{15}H_{22}O_7$: C, 57.32; H, 7.05. Found: C, 57.30; H, 7.01.

Compound 2c′. Compound **2c′** was isolated in a 75% yield as a light yellow syrup. $[\alpha]_D = +120.36$ (c 0.5, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$, TMS): δ 6.42 (dd, 1H, J = 1.48, 17.09 Hz, olefinic), 6.15 (dd, 1H, J = 10.40, 17.09 Hz, olefinic), 5.85 (dd, 1H, J = 1.48, 10.40 Hz, olefinic), 5.39 (s, 1H, olefinic), 5.28 (s, 1H, olefinic), 4.88 (s, 1H, H-1), 4.85−4.76 (m, 3H, H-3, OCH_2), 4.52 (d, 1H, J = 5.20 Hz, H-2), 4.44 (d, 1H, J = 8.17 Hz, H-5), 3.9 (dd, 1H, J = 3.76, 8.17 Hz, H-4), 3.30 (s, 3H, OMe), 1.49 (s, 3H, CH_3), 1.30 (s, 3H, CH_3). IR (neat): ν 3444, 2989, 2940, 1728, 1635, 1408, 1382, 1094, 869. ES-MS: m/z 315 ($M^+ + 1$). Anal. Calcd for $C_{15}H_{22}O_7$: C, 57.32; H, 7.05. Found: C, 57.28; H, 7.02.

Compound 2d. Compound **2d** was isolated in a 67% yield as a dark syrup. $[\alpha]_D = +102.24$ (c 0.32, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ 6.07 (s, 1H, olefinic), 5.02 (s, 1H, H-1), 4.90 (br. s, 2H, OCH_2), 4.70−4.61 (m, 2H, H-3, H-5), 4.56 (d, 1H, J = 5.87 Hz, H-2), 4.18 (br. s, 1H, H-4), 3.49 (s, 3H, OMe), 1.48 (s, 3H, CH_3), 1.30 (s, 3H, CH_3). IR (neat): ν 3421, 2937, 1747, 1638, 1379, 1211, 1093, 866. ^{13}C NMR (75 MHz, $CDCl_3$, TMS): δ 172.5, 167.0, 116.8,

110.2, 90.1, 85.6, 79.7, 71.6, 69.7, 56.2, 51.0, 26, 24.5. FAB-MS: *m/z* 287 ($M^+ + 1$). Anal. Calcd for $C_{13}H_{18}O_7$: C, 54.54; H, 6.34. Found: C, 54.51; H, 6.28.

Compound 2d′. Compound **2d′** was isolated in a 65% yield as a dark syrup. $[\alpha]_D = +61.08$ (*c* 0.2, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$, TMS): δ 6.08 (br. s, 1H, olefinic), 4.85 (br. s, 3H, H-1, OCH_2),4.79 (dd, 1H, $J = 3.71$, 5.94 Hz, H-3), 4.73 (d, 1H, $J = 9.66$ Hz, H-5), 4.50 (d, 1H, $J = 5.94$ Hz, H-2), 3.9 (dd, 1H, $J = 3.71$, 8.9 Hz, H-4), 3.28 (s, 3H, OMe), 1.42 (s, 3H, CH_3), 1.28 (s, 3H, CH_3). IR (neat): ν 3425, 2938, 1750, 1639, 1382, 1215, 1096, 862. ^{13}C NMR (75 MHz, $CDCl_3$, TMS): δ 172.3, 167.4, 116.4, 110.3, 90.2, 85.8, 79.2, 72.1, 68.9, 56.3, 51.2, 25.8, 23.8. FAB-MS: *m/z* 287 ($M^+ + 1$). Anal. Calcd for $C_{13}H_{18}O_7$: C, 54.54; H, 6.34. Found: C, 54.50; H, 6.30.

Compound 2e. Compound **2e** was isolated in an 84% yield as a colorless syrup. $[\alpha]_D = +144.44$ (*c* 0.45, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$, TMS): δ 5.28 (s, 2H, olefinic), 4.92 (s, 1H, H-1), 4.8 (d, 1H, $J = 5.43$ Hz, H-3), 4.55 (d, 1H, $J = 5.43$ Hz, H-2), 4.45 (br. s, 1H, H-5), 4.2 (br. s, 2H, OCH_2), 3.8 (d, 1H, $J = 2.32$ Hz, H-4), 3.45 (s, 3H, OMe), 1.48 (s, 3H, CH_3), 1.3 (s, 3H, CH_3), 0.9 (s, 9H, 3 × CH_3), 0.06 (s, 6H, 2 × CH_3). IR (neat): ν 3447, 2945, 2872, 1670, 1465, 1385, 1245, 1092, 851. ES-MS: *m/z* 375 ($M^+ + 1$). Anal. Calcd for $C_{18}H_{34}O_6Si$: C, 57.72; H, 9.15. Found: C, 57.68; H, 9.10.

Compound 2e′. Compound **2e′** was isolated in an 84% yield as a colorless syrup. $[\alpha]_D = +112.40$ (*c* 0.5, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$, TMS): δ 5.22 (s, 2H, olefinic), 4.85 (s, 1H, H-1), 4.82 (dd, 1H, $J = 3.88$, 6.21 Hz, H-3), 4.52 (d, 1H, $J = 6.21$ Hz, H-2), 4.46−4.2 (m, 3H, OCH_2, H-5), 3.88 (dd, 1H, $J = 3.88$, 8.54 Hz, H-4), 3.2 (s, 3H, OMe), 2.89 (d,1H, $J = 6.21$ OH), 1.40 (s, 3H, CH_3), 1.24 (s, 3H, CH_3), 0.82 (s, 9H, 3 × CH_3), 0.05 (s, 6H, 2 × CH_3). IR (neat): ν 3448, 2960, 2872, 1665, 1465, 1382, 1260, 1091, 855. ES-MS: *m/z* 375 ($M^+ + 1$). Anal. Calcd for $C_{18}H_{34}O_6Si$: C, 57.72, H; 9.15. Found: C, 57.66; H, 9.09.

Compound 2f. Compound **2f** was isolated in an 86% yield as a light yellow syrup. $[\alpha]_D = +157.71$ (*c* 1.05, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$, TMS): δ 6.4 (dd, 1H, $J = 2.2$, 16.89 Hz, olefinic), 6.13 (dd, 1H, $J = 10.28$, 16.89, Hz, olefinic), 5.84 (dd, 1H, $J = 2.2$, 10.28 Hz, olefinic), 5.4 (d, 1H, $J = 7.34$ Hz, H-5), 5.34 (s, 1H, olefinic), 5.20 (s, 1H, olefinic), 4.88 (s, 1H, H-1), 4.65 (d, 1H, $J = 5.87$ Hz, H-3), 4.5 (d, 1H, $J = 5.87$ Hz, H-2), 4.38 (d, 1H, $J = 7.34$ Hz, H-4), 4.22 (s, 2H, OCH_2), 3.25 (s, 3H, OMe), 1.45 (s, 3H, CH_3), 1.30 (s, 3H, CH_3), 0.90 (s, 9H, 3 × CH_3), 0.06 (s, 6H, 2 × CH_3). IR (neat): ν 2932, 2857, 1731, 1632, 1460, 1378, 849. ES-MS: *m/z* 429 ($M^+ + 1$); Anal. Calcd for $C_{21}H_{36}O_7Si$: C, 58.85; H, 8.47. Found: C, 58.81; H, 8.42.

Compound 2f′. Compound **2f′** was isolated in an 86% yield as a colorless syrup. $[\alpha]_D = +86.67$ (*c* 0.4, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$, TMS): δ 6.4 (dd, 1H, $J = 2.4$, 17.63 Hz, olefinic), 6.10 (dd, 1H, $J = 10.42$, 17.63 Hz, olefinic), 5.80 (dd, 1H, $J = 2.4$, 10.42 Hz, olefinic), 5.35−5.2 (m, 3H, H-5, olefinic), 4.84 (s, 1H, H-1), 4.66 (dd, 1H, $J = 3.2$, 5.61 Hz, H-3), 4.5 (d, 1H, $J = 5.61$ Hz, H-2), 4.25 (br. s, 2H, OCH_2,), 4.08 (dd, 1H, $J = 3.2$, 9.62 Hz, H-4), 3.29 (s, 3H, OMe), 1.45 (s, 3H, CH_3), 1.25 (s, 3H, CH_3), 0.9 (s, 9H, 3 × CH_3), 0.05 (s, 6H, 2 × CH_3). IR (neat): ν 2938, 2860, 1725, 1625, 1460, 1375, 851. ES-MS: *m/z* 429 ($M^+ + 1$). Anal. Calcd for $C_{21}H_{36}O_7Si$: C, 58.85; H, 8.47. Found: C, 58.80; H, 8.41.

Compound 2g. Compound 2g was isolated in a 62% yield as a dark syrup. $[\alpha]_D = -18.49$ (*c* 0.75, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$, TMS): δ 6.0 (br. s, 1H, olefinic), 5.0−4.93 (m, 2H, H-1, H-5), 4.8−4.7 (m, 2H, OCH_2, H-3), 4.58 (d, 1H, $J = 5.94$ Hz, H-2), 4.44 (dd, 1H, $J = 1.48$, 17.83 Hz, OCH_2), 3.92 (d, 1H, $J = 10.40$ Hz, H_4), 3.35 (s, 3H, OMe), 1.40 (s, 3H, CH_3), 1.24 (s, 3H, CH_3), 0.88 (s, 9H, 3 × CH_3), 0.05 (s, 6H, 2 × CH_3). IR (neat): ν 2930, 2856, 1761, 1639, 1379, 1258, 1101, 844. ^{13}C NMR (75 MHz, $CDCl_3$, TMS): δ 173.4, 171.9, 116.8, 112.9, 111.6, 88.1, 85.0, 82.8, 81.2, 61.0, 56.8, 27.0, 26.2 (3C), 25.5, 18.8, −4.8 (2C). FAB-MS: *m/z* 401 ($M^+ + 1$). Anal. Calcd for $C_{19}H_{32}O_7$: C, 56.97; H, 8.05. Found: C, 56.91; H, 8.01.

Compound 2g′. Compound **2g′** was isolated in a 61% yield as a dark syrup. $[\alpha]_D = +33.08$ (*c* 0.7, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$, TMS): δ 6.0 (br. s, 1H, olefinic), 5.1 (d, 1H, $J = 8.91$ Hz, H-5), 4.90 (s, 1H, H-1), 4.82 (dd, $J = 3.71$, 5.94 Hz, H-3), 4.70 (dd, 1H, $J = 2.23$, 17.83 Hz, OCH_2), 4.5−4.3 (m, 2H, H-2, OCH_2), 3.69 (dd, 1H, $J = 3.71$, 8.91 Hz, H-4), 3.33 (s, 3H, OMe), 1.40 (s, 3H, CH_3), 1.28 (s, 3H, CH_3), 0.88 (s, 9H, 3 × CH_3), 0.05 (s, 6H, 2 × CH_3). IR (neat): ν 2936, 2859, 1763, 1648, 1378, 1260, 1105, 848. ^{13}C NMR (75 MHz, $CDCl_3$, TMS): δ 173.2, 171.8, 116.7, 112.8, 112.0, 88.4, 85.4, 83.2, 81.5, 61.4, 56.9, 27.4, 26.3 (3C), 25.7, 18.5, −5.0 (2C). FAB-MS: *m/z* 401 ($M^+ + 1$). Anal. Calcd for $C_{19}H_{32}O_7$: C, 56.97; H, 8.05. Found: C, 56.92; H, 8.02.

Compounds 3a and 3a′. Compounds **3a** and **3a′** were isolated in 44.8 and ′17.05% yields, respectively, as a colorless syrups. Compound **3a**. $[\alpha]_D = -163.12$ (*c* 0.85, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$, TMS): δ 6.42 (s, 1H, olefinic), 6.07 (s, 1H, olefinic), 4.98 (s, 1H, H-1), 4.68 (d, 1H, $J = 5.94$ Hz, H-3), 4.58−4.49 (m, 2H, H-2, H-5), 4.22 (q, 2H, $J = 6.68$ Hz, OCH_2), 4.08 (br.s, 1H, H-4) 3.49 (s, 1H, OMe), 1.51 (s, 3H, CH_3), 1.42 (s, 3H, CH_3), 1.3 (t, 3H, $J = 6.68$ Hz, CH_3). IR (neat): ν 3426, 2981, 2934, 1718, 1645, 1450, 1378, 1322, 1088, 956. ES-MS: *m/z* 303 ($M^+ + 1$). Anal. Calcd for $C_{14}H_{22}O_7$: C, 55.62; H, 7.33. Found: C, 55.61; H, 7.29. Compound **3a′**. $[\alpha]_D = -125.60$ (*c* 0.5, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$, TMS): δ 6.32 (s, 1H, olefinic), 5.93 (s, 1H, olefinic), 4.84 (s, 1H, H-1), 4.80−4.7 (m, 2H, H-5, H-3), 4.51 (d, 1H, $J = 6.04$, H-2), 4.24 (q, 2H, $J = 6.04$, OCH_2), 4.08 (dd, 1H, $J = 3.02$, 7.55, H-4), 3.28 (s, 3H, OMe), 1.51 (s, 3H, CH_3), 1.42 (s, 3H, CH_3), 1.3 (t, 3H, $J = 6.04$, CH_3). IR (neat): ν 3428, 2987, 2942, 1716, 1636, 1454, 1378, 1321, 1162, 1092. ES-MS: *m/z* 303 ($M^+ + 1$). Anal. Calcd for $C_{14}H_{22}O_7$: C, 55.62; H, 7.33. Found: C, 55.58; H, 7.28.

Compound 3b. Compound 3b was isolated in a 63% yield as a colorless syrup. $[\alpha]_D = -171.26$ (*c* 0.9, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$, TMS): δ 5.3 (s, 1H, olefinic), 5.28 (s, 1H, olefinic), 4.95 (s, 1H, H-1), 4.80 (d, 1H, H-3), 4.54 (d, 1H, H-2), 4.48 (d, 1H, H-5), 4.2 (br s, 2H, OCH_2), 3.93 (br. s, 1H, H-4), 3.45 (s, 3H, OMe), 1.45 (s, 3H, CH_3), 1.30 (s, 3H, CH_3). IR (neat): ν 3415, 2944, 1670, 1455, 1384,

1095, 868. ES-MS: *m*/*z* 261 ($M^+ + 1$). Anal. Calcd for $C_{12}H_{20}O_6$: C, 55.37; H, 7.74. Found: C, 55.35; H, 7.73.

Compound 3b′. Compound **3b′** was isolated in a 63% yield as a white solid. mp: 106 °C. $[\alpha]_D = -42.05$ (*c* 0.9, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ 5.3 (s, 1H, olefinic), 5.25 (s, 1H, olefinic), 4.9 (s, 1H, H-1), 4.84 (dd, 1H, $J = 3.77$, 6.04 Hz, H-3), 4.55−4.45 (m, 2H, H-2, H-5), 4.2 (br. s, 2H, OCH_2), 3.98 (dd, 1H, $J = 3.02$, 8.3 Hz, H-4), 3.30 (s, 3H, OMe), 1.46 (s, 3H, CH_3), 1.3 (s, 3H, CH_3). IR (KBr): ν 3413, 2942, 1680, 1458, 1382, 1093, 1025, 863. ES-MS: *m*/*z* 261 ($M^+ + 1$). Anal. Calcd for $C_{12}H_{20}O_6$: C, 55.37; H, 7.74. Found: C, 55.33; H, 7.71.

Compound 3c. Compound **3c** was Isolated in a 75% yield as a light yellow syrup. $[\alpha]_D = -147.46$ (*c* 2.05, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ 6.45 (dd, 1H, $J =$ 2.26, 17.37 Hz, olefinic), 6.15 (dd, 1H, $J = 10.57$, 17.37 Hz, olefinic), 5.85 (dd, 1H, $J = 2.26$, 10.57 Hz, olefinic), 5.5 (s, 1H, olefinic), 5.4 (s, 1H, olefinic), 4.97 (s, 1H, H-1), 4.78 (d, 1H, $J = 6.04$ Hz, H-3), 4.7 (d, 2H, $J = 5.29$ Hz, OCH_2), 4.54 (d, 1H, $J = 6.04$ Hz, H-2), 4.49 (br.s, 1H, H-5), 4.25 (s, 1H, OH), 3.88 (br.s, 1H, H-4), 3.48 (s, 3H, OMe), 1.45 (s, 3H, CH_3), 1.30 (s, 3H, CH_3). IR (neat): ν 3442, 2986, 2942, 1730, 1645, 1412, 1380, 1093, 865. ES-MS: *m*/*z* 315 ($M^+ + 1$). Anal. Calcd for $C_{15}H_{22}O_7$: C, 57.32; H, 7.05. Found: C, 57.31; H, 7.04.

Compound 3c′. Compound **3c′** was isolated in a 75% yield as a light yellow syrup. $[\alpha]_D = -119.5$ (*c* 0.2, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ 6.45 (dd, 1H, $J =$ 2.26, 17.37 Hz, olefinic), 6.15 (dd, 1H, $J = 10.57$, 17.37 Hz, olefinic), 5.85 (dd, 1H, $J = 2.26$, 10.57 Hz, olefinic), 5.4 (s, 1H, olefinic), 5.28 (s, 1H, olefinic), 4.90−4.78 (m, 4H, H-1, H-3, OCH_2), 4.52 (d, 1H, $J = 6.04$ Hz, H-2), 4.48 (d, 1H, $J = 8.9$ Hz, H-5), 3.9 (dd, 1H, $J = 6.04$, 8.9 Hz, H-4), 3.30 (s, 3H, OMe), 1.45 (s, 3H, CH_3),1.30 (s, 3H, CH_3). IR (neat): ν 3447, 2938, 2940, 1729, 1645, 1407, 1379, 1260, 1096, 845. ES-MS: *m*/*z* 315 ($M^+ + 1$). Anal. Calcd for $C_{15}H_{22}O_7$: C, 57.32; H, 7.05. Found: C, 57.29; H, 6.98.

Compound 3d. Compound **3d** was isolated in a 66% yield as a dark syrup. $[\alpha]_D = -132.85$ (*c* 0.45, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$, TMS): δ 6.05 (br. s, 1H, olefinic), 5.0 (s, 1H, H-1), 4.90 (s, 2H, OCH_2), 4.69 (d, 1H, $J = 5.94$ Hz, H-3), 4.55 (d, 1H, $J = 5.94$ Hz, H-2), 4.4 (br. s, 1H, H-5), 4.2 (br. s, 1H, H-4), 3.50 (s, 3H, OMe), 1.45 (s, 3H, CH_3), 1.30 (s, 3H, CH_3). IR (neat): ν 3420, 2937, 1748, 1635, 1378, 1210, 1094, 860. ^{13}C NMR (75 MHz, $CDCl_3$, TMS): δ 172.4, 167.0, 116.7, 110.4, 90.2, 85.8, 80.2, 71.5, 69.8, 56.0, 51.2, 26.1, 24.8. FAB-MS: *m*/*z* 287 ($M^+ + 1$). Anal. Calcd for $C_{13}H_{18}O_7$: C, 54.54; H, 6.34. Found: C, 54.49; H, 6.27.

Compound 3d′. Compound **3d′** was isolated in a 64% yield as a dark syrup. $[\alpha]_D = -41.68$ (*c* 0.35, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$, TMS): δ 6.15 (s, 1H, olefinic), 4.92 (br. s, 3H, H-1, OCH_2), 4.88−4.70 (m, 2H, H-3, H-5), 4.58 (d, 1H, $J = 5.48$ Hz, H-2), 3.95 (dd, 1H, $J = 3.91$, 8.61 Hz, H-4), 3.30 (s, 3H, OMe), 1.48 (s, 3H, CH_3), 1.30 (s, 3H, CH_3). IR (neat): ν 3430, 2940, 1752, 1640, 1384, 1218, 1098, 864. ^{13}C NMR (75 MHz, $CDCl_3$, TMS): δ 172.2, 167.4, 116.9, 110.2, 90.4, 85.4, 80.1, 71.6, 69.7, 56.2, 51.3, 26.4, 25.1. FAB-MS: *m*/*z* 287 ($M^+ + 1$). Anal. Calcd for $C_{13}H_{18}O_7$: C, 54.54; H, 6.34. Found: C, 54.53; H, 6.32.

Compound 3e. Compound **3e** was isolated in an 84% yield as a colorless syrup. $[\alpha]_D = -135.74$ (*c* 1.95, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ 5.24 (br. s, 2H, olefinic), 4.9 (s, 1H, H-1), 4.78 (d, 1H, $J = 6.04$ Hz, H-3), 4.58 (d, 1H, $J = 6.04$ Hz, H-2), 4.47 (br. s, 1H, H-5), 4.22−4.18 (m, 2H, OCH_2), 3.75 (d, 1H, $J = 3.02$ Hz, H-4), 3.45 (s, 3H, OMe), 1.45 (s, 3H, CH_3), 1.3 (s, 3H, CH_3), 0.9 (s, 9H, 3 × CH_3), 0.06 (s, 6H, 2 × CH_3). IR (neat): ν 3448, 2934, 2858, 1655, 1466, 1378, 1255, 1096, 841. ES-MS: *m*/*z* 375 ($M^+ + 1$). Anal. Calcd for $C_{18}H_{34}O_6Si$: C, 57.72; H, 9.15. Found: C, 57.70; H, 9.13.

Compound 3e′. Compound **3e′** was isolated in an 84% yield as a colorless syrup. $[\alpha]_D = -125.48$ (*c* 0.5, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 5.22 (br. s, 2H, olefinic), 4.86 (s, 1H, H-1), 4.82 (dd, 1H, $J = 3.57$, 5.72 Hz, H-3), 4.5 (d, 1H, $J = 5.72$ Hz, H-2), 4.4−4.38 (m, 1H, H-5), 4.35 (d, 1H, $J = 12.87$ Hz, OCH_2), 4.24 (d, 1H, $J =$ 12.87 Hz, OCH_2), 3.95 (dd, 1H, $J = 3.57$, 7.86 Hz, H-4), 3.3 (s, 3H, OMe), 3.0 (d, 1H, $J = 5.72$, OH), 1.5 (s, 3H, olefinic), 1.33 (s, 3H, olefinic), 0.9 (s, 9H, 3 × CH_3), 0.06 (s, 6H, 2 × CH_3). IR (neat): ν 3442, 2939, 2865, 1662, 1465, 1360, 1256, 1095, 849. ES-MS: *m*/*z* 375 ($M^+ + 1$). Anal. Calcd for $C_{18}H_{34}O_6Si$: C, 57.72; H, 9.15. Found: C, 57.71; H, 9.14.

Compound 3f. Compound **3f** was isolated in an 86% yield as a colorless syrup. $[\alpha]_D = -159.69$ (*c* 1.3, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$, TMS): δ 6.45 (dd, 1H, $J = 2.23$, 17.83 Hz, olefinic), 6.16 (dd, 1H, $J = 10.40$, 17.83 Hz, olefinic), 5.86 (dd, 1H, $J = 2.23$, 10.40 Hz, olefinic), 5.42 (d, 1H, $J = 6.68$ Hz, H-5), 5.35 (s, 1H, olefinic), 5.20 (s, 1H, olefinic), 4.90 (s, 1H, H-1), 4.65 (d, 1H, $J = 5.94$ Hz, H-3), 4.52 (d, 1H, $J = 5.94$ Hz, H-2), 4.38 (d, 1H, $J = 8.17$ Hz, H-4), 4.22 (br. s, 2H, OCH_2), 3.25 (s, 3H, OMe), 1.45 (s, 3H, CH_3), 1.3 (s, 3H, CH_3), 0.9 (s, 9H, 3 × CH_3), 0.06 (s, 6H, 2 × CH_3). IR (neat): ν 2942, 2870, 1720, 1635, 1470, 1365, 855. ES-MS: *m*/*z* 429 ($M^+ + 1$). Anal. Calcd for $C_{21}H_{36}O_7Si$: C, 58.83; H, 8.45. Found: C, 58.81; H, 8.42.

Compound 3f′. Compound **3f′** was isolated in an 86% yield as a colorless syrup. $[\alpha]_D = -110.6$ (*c* 1.05, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ 6.4 (dd, 1H, $J = 2.23$, 17.83 Hz, olefinic), 6.10 (dd, 1H, $J = 10.05$, 17.37 Hz, olefinic), 5.8 (dd, 1H, $J = 2.26$, 10.40 Hz, olefinic), 5.40−5.20 (m, 3H, olefinic, H-5), 4.88 (s, 1H, H-1), 4.66 (dd, 1H, $J = 3.2$, 5.62 Hz, H-3), 4.48 (d, 1H, $J = 5.62$ Hz, H-2), 4.32−4.22 (m, 2H, OCH_2), 4.05 (dd, 1H, $J = 3.2$, 9.62 Hz, H-4), 3.3 (s, 3H, OMe), 1.45 (s, 3H, CH_3), 1.3 (s, 3H, CH_3), 0.9 (s, 9H, 3 × CH_3), 0.06 (s, 6H, 2 × CH_3). IR (neat): ν 2935, 2860, 1728, 1636, 1465, 1381, 856. ES-MS: *m*/*z* 429 ($M^+ + 1$). Anal. Calcd for $C_{21}H_{36}O_7Si$: C, 58.85; H, 8.47. Found: C, 58.82; H, 8.44.

Compound 3g. Compound **3g** was isolated in a 60% yield as a dark syrup. $[\alpha]_D = +14.42$ (*c* 0.7, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$, TMS): δ 6.05 (br.s, 1H, olefinic), 4.95 (br. s, 2H, H-1, H-5), 4.78 (dd, 1H, $J = 2.26$, 18. 12 Hz, OCH_2), 4.60 (d, 1H, $J = 6.04$, H-2), 4.4 (dd, 1H, $J = 2.26$, 18. 12 Hz, OCH_2), 3.93 (d, 1H, $J = 9.06$ Hz, H-4), 3.42 (s, 3H, Ome), 1.45 (s, 3H, CH_3), 1.3 (s, 3H, CH_3), 0.9 (s, 9H,

3 × CH_3), 0.06 (s, 6H, 2 × CH_3). IR (neat): *ν* 2935, 2858, 1762, 1645, 1370, 1255, 1102, 846. ^{13}C NMR (75 MHz, $CDCl_3$, TMS): *δ* 173.5, 171.7, 115.8, 113.4, 107.9, 84.6, 80.5, 80.1, 78.5, 60.1, 54.8, 26.2, 26.0 (3C), 24.8, 17.89, −5.2 (2C). FAB-MS: *m*/*z* 401 ($M^+ + 1$). Anal. Calcd for $C_{19}H_{32}O_7$: C, 56.97; H, 8.05. Found: C, 56.93; H, 8.03.

Compound 3g′. Compound **3g′** was isolated in a 61% yield as a dark syrup. $[\alpha]_D = -91.05$ (*c* 0.55, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$, TMS): *δ* 6.1 (br. s, 1H, olefinic), 5.1 (d, 1H, $J = 8.91$ Hz, H-5), 4.90 (s, 1H, H-1), 4.85 (m, 1H, H-3), 4.70 (dd, 1H, $J = 3.71$, 17.92 Hz, OCH_2), 4.6−4.4 (m, 2H, OCH_2, H-2), 3.7 (dd, 1H, $J = 3.71$, 8.91 Hz, H-4), 3.3 (s, 3H, OMe), 1.45 (s, 3H, CH_3), 1.3 (s, 3H, CH_3), 0.9 (s, 9H, 3 × CH_3), 0.06 (s, 6H, 2 × CH_3). IR (neat): *ν* 2938, 2860, 1764, 1650, 1379, 1262, 1108, 850. ^{13}C NMR (75 MHz, $CDCl_3$, TMS): *δ* 173.7, 171.9, 115.9, 113.1, 108.2, 84.4, 80.3, 80.0, 78.3, 60.0, 54.8, 24.6, 25.8 (3C), 26.1, 18.1, −5.5 (2C). FAB-MS: *m*/*z* 401 ($M^+ + 1$). Anal. Calcd for $C_{19}H_{32}O_7$: C, 56.97; H, 8.05. Found: C, 56.95; H, 8.04.

Compound 2i′. ^{1}H NMR (300 MHz, $CDCl_3$, TMS): *δ* 4.97 (s, 0.33H, H-1), 4.95 (s, 0.67H, H-1), 4.92−4.79 (m, 1.33H, H-3, H-5), 4.69−4.66 (m, 0.67H, H-3), 4.6 (d, 1H, $J = 6.04$ Hz, H-2), 4.17 (dd, 0.33H, $J = 3.39$, 9.44 Hz, H-4), 4.04 (dd, 0.67H, $J = 3.39$, 6.04 Hz, H-4), 3.84−3.68 (m, 2H, OCH_2), 3.37 (s, 1H, OMe) 3.33 (s, 2H, OMe), 3.0−2.60 (m, 2H), 2.49−2.34 (m, 1H), 1.48 (s, 3H, CH_3), 1.33 (s, 1H, CH_3), 1.32(s, 2H, CH_3).

Compound 2h′. ^{1}H NMR (200 MHz, $CDCl_3$, TMS): *δ* 4.92 (s, 1H, H-1), 4.78 (d, 1H, H-3), 4.54 (d, 1H, $J = 6.04$ Hz, H-2), 4.46−4.04 (m, 2H, OCH_2), 3.84−3.72 (m, 1H, H-5), 3.63−3.53 (m, 1H, H-4), 3.46 (s, 0.99H, OMe), 3.45 (s, 2.01H, OMe), 2.78−2.52 (m, 2H), 2.37−2.13 (m, 1H), 1.44 (s, 3H, CH_3), 1.30 (s, 3H, CH_3).

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