Sequential One-Pot Isomerization–Wittig Olefination–Hydrogenation

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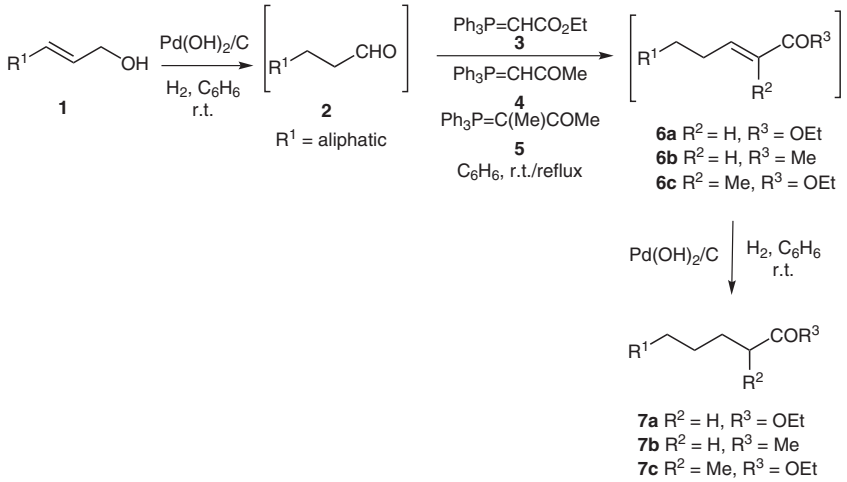
Abstract: Primary allylic alcohols are isomerized to aldehydes in the presence of $Pd(OH)_2$ and homologated to α,β-unsaturated carbonyl derivatives in one-pot by addition of stabilized Wittig ylides in a sequential fashion. When the reaction was prolonged by addition of more catalyst, a hydrogenation step succeeds the Wittig olefination. In addition, sequential isomerization–Wittig olefination–oxa-Michael addition reaction provides tetrahydropyran with high diastereoselectivity.

Key words: isomerization, Wittig olefination, hydrogenation, oxa-Michael reaction, aldehydes

Aldehydes are important and extremely versatile synthetic intermediates for various pharmaceuticals, agrochemicals, and other fine chemicals.[1] They can be converted into alcohols, amines, carboxylic acids, and other derivatives. These conversions become difficult when the intermediate aldehydes are unstable leading to decomposition,[2,3] polymerization,[4] or face difficulty in isolation due to volatility and toxicity. Such problems can be overcome by preparing the aldehydes and reacting them in situ with other reagents. The conversion of multistep reactions into economically and environmentally favored one-pot processes,[5–7] is a challenging task in synthetic organic chemistry and has potential use in natural product synthesis. Therefore, domino reaction under isomerization conditions is a clean and economical method of obtaining functionalized organic molecules. In continuation of our work on the development of a new method for the isomerization of allylic alcohols,[8] we herein report for the first time $Pd(OH)_2$-catalyzed sequential one-pot isomerization–Wittig olefination as well as the first, one-pot isomerization–Wittig olefination–hydrogenation and one-pot isomerization–Wittig olefination–oxa-Michael addition reactions of allylic alcohols.

When an allylic alcohol **1** was subjected to isomerization conditions [7 mol% preactivated $Pd(OH)_2$/C, benzene, r.t.][8] in the presence of stabilized ylide **3**, the α,β-unsaturated ester **6a** was isolated in 10% yield along with a good amount of starting material. However, when stabilized ylide **3** was added to the same pot after the isomerization of the allylic alcohol **1** [catalyzed by preactivated $Pd(OH)_2$/C] to aldehyde **2**, the exclusive formation of α,β-unsaturated ester **6a** in very good yield was noted (Scheme 1). Thus, the isomerization of the allylic alcohol, as well as the olefination of the aldehyde **2**, have been performed as a one-pot process.

Once the protocol was standardized, we carried out this transformation with other allylic alcohols using different ylides (Table 1). In the case of ylide **3**, the Wittig olefination reaction occurred at room temperature, whereas other ylides **4** and **5** required refluxing conditions after the isomerization was complete. All reactions were clean and efficient giving good yields of unsaturated carbonyl deriv-



Scheme 1 Sequential isomerization–Wittig olefination–hydrogenation

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atives **6**. Allylic alcohols having PMB and TBS groups (Table 1) require the addition of 5 mol% of Et_3N to avoid deprotection.

After the isomerization of the allylic alcohol **1** as well as the olefination of the aldehyde **2** to α,β-unsaturated ester **6** using ylide **3** or **4** have been performed as a one-pot process, another 7 mol% of $Pd(OH)_2/C$ was added to the flask under nitrogen atmosphere, the atmosphere again replaced with hydrogen gas and the stirring continued at room temperature, which resulted in the formation of saturated carbonyl derivative **7a** or **7b**, respectively (Scheme 1). Hence, a sequential process involving three separate steps had occurred in one step. The initial step is an isomerization of allylic alcohol **1** to give the aldehyde **2** followed by Wittig olefination to furnish unsaturated ester or enone **6**, which was finally hydrogenated in the same pot to give the saturated ester or ketone **7** (Table 1).

Thus, the same catalyst, that had catalyzed the initial isomerization step, acted as a hydrogenation catalyst in the final hydrogenation reaction of this three-step process. All three stages, viz., the isomerization of the allylic alcohol, the olefination of the aldehyde, and the hydrogenation of the Wittig product, have been performed as a one-pot process. It is important to mention that in the case of the isomerization of allylic alcohols in the presence of alkyl-substituted stabilized ylides such as **5**, the reaction stops at the Wittig olefination stage and does not undergo final hydrogenation reaction. However, enoate **6c** obtained from ylide **5**, after isolation undergoes hydrogenation affording **7c** in good yields (Scheme 1). The results are shown in Table 1.

Table 1 $Pd(OH)_2$-Catalyzed Sequential One-Pot Isomerization–Wittig Olefination and Sequential One-Pot Isomerization–Wittig Olefination–Hydrogenation[a]

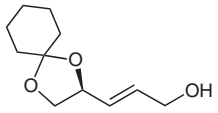
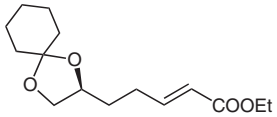
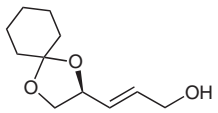
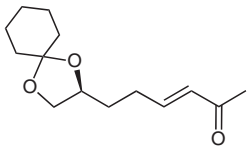
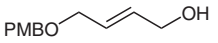
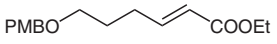
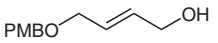
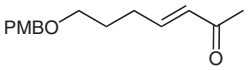
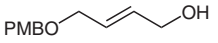
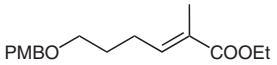
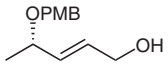
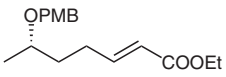
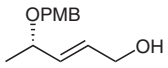
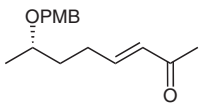
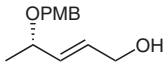
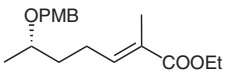
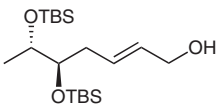
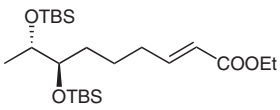
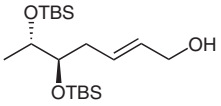
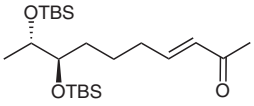
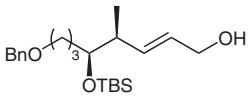
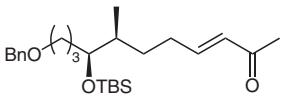
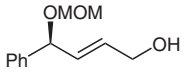
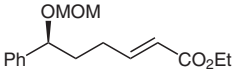
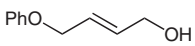
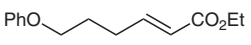
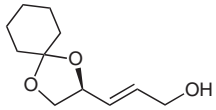
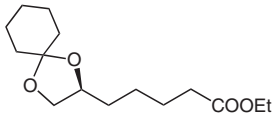
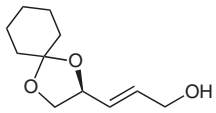
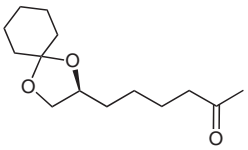
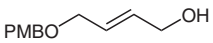
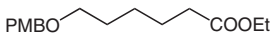
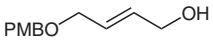
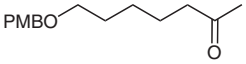
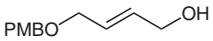
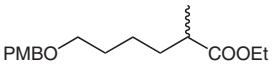
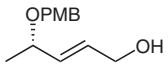
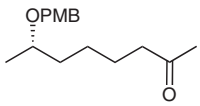
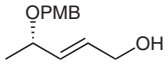
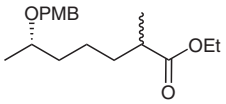
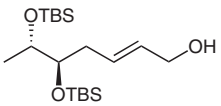
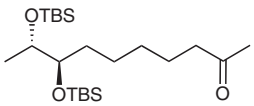
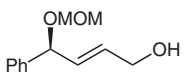
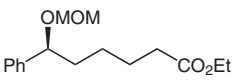
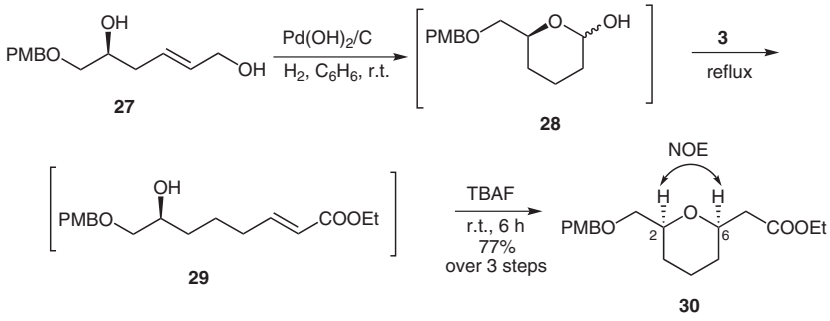
Allylic alcohol	Ylide	Product	Time (h)	Temp	Yield (%)[b]
 **8**	$Ph_3P{=}CHCO_2Et$ **3**	 **9a**	1.5	r.t.	89
 **8**	$Ph_3P{=}CHCOMe$ **4**	 **9b**	3.5	reflux	88
 **10**	$Ph_3P{=}CHCO_2Et$ **3**	 **11a**	1.5	r.t.	86
 **10**	$Ph_3P{=}CHCOMe$ **4**	 **11b**	3.5	reflux	84
 **10**	$Ph_3P{=}C(Me)CO_2Et$ **5**	 **11c**	4.5	reflux	83
 **12**	$Ph_3P{=}CHCO_2Et$ **3**	 **13a**	1.5	r.t.	89
 **12**	$Ph_3P{=}CHCOMe$ **4**	 **13b**	3.5	reflux	87
 **12**	$Ph_3P{=}C(Me)CO_2Et$ **5**	 **13c**	4.5	reflux	84
 **14**	$Ph_3P{=}CHCO_2Et$ **3**	 **15a**	1.5	r.t.	85

Table 1 $Pd(OH)_2$-Catalyzed Sequential One-Pot Isomerization–Wittig Olefination and Sequential One-Pot Isomerization–Wittig Olefination–Hydrogenation[a] (continued)

Allylic alcohol	Ylide	Product	Time (h)	Temp	Yield (%)[b]
 **14**	Ph_3P=CHCOMe **4**	 **15b**	3.5	reflux	83
 **16**	Ph_3P=CHCOMe **4**	 **17b**	3.5	reflux	82
 **18**	Ph_3P=$CHCO_2Et$ **3**	 **19a**	1.5	r.t.	88
 **20**	Ph_3P=$CHCO_2Et$ **3**	 **21a**	1.5	r.t.	86
 **8**	Ph_3P=$CHCO_2Et$ **3**	 **22a**	6.0	r.t.[d]	86
 **8**	Ph_3P=CHCOMe **4**	 **22b**	8.5	r.t.[d]	86
 **10**	Ph_3P=$CHCO_2Et$ **3**	 **23a**	6.0	r.t.[d]	84
 **10**	Ph_3P=CHCOMe **4**	 **23b**	8.0	r.t.[d]	83
 **10**	Ph_3P=CH(Me)CO_2Et **5**	 **23c**[c]	6.0	r.t.[d]	84
 **12**	Ph_3P=CHCOMe **4**	 **24b**	8.5	r.t.[d]	85
 **12**	Ph_3P=CH(Me)CO_2Et **5**	 **24c**[c]	8.5	r.t.[d]	81
 **14**	Ph_3P=CHCOMe **4**	 **25b**	8.5	r.t.[d]	80
 **18**	Ph_3P=$CHCO_2Et$ **3**	 **26a**	6.0	r.t.[d]	80

[a] Reactions were performed with $Pd(OH)_2$ and stabilized Wittig ylides.
[b] Yields of products after purification.
[c] Final hydrogenation reaction was done after isolating the Wittig product.
[d] Final hydrogenation reaction was performed at r.t.



Scheme 2 Sequential isomerization–Wittig reaction–oxa-Michael reaction

Substituted tetrahydropyrans having 2,6-*syn* configuration are found to be important structural motifs present in numerous natural products such as spirastrellolides A and B,[9] (–)-centrolobine,[10] (–)-exiguolide,[11] and bioactive synthons[12] (Figure 1). Thus, we envisaged the synthesis of such tetrahydropyrans by exploiting the above developed methodology. When the isomerization of the allyl alcohol **27** having free secondary hydroxyl group was performed, the stabilized ylide **3** was added to the corresponding lactol **28** in the same pot, which resulted in the formation of hydroxyester **29**. When the reaction was continued, after the addition of excess TBAF, it subsequently underwent intramolecular oxa-Michael reaction in highly diastereoselective[8,13] fashion to furnish 2,6-*syn* tetrahydropyran **30** as the sole product in 77% yield (over three steps) (Scheme 2).

The relative *syn* relationship at C-2 and C-6 was confirmed through NOE experiments. Thus, all three stages, the isomerization of the allylic alcohol, the olefination of the lactol, and the oxa-Michael cyclization of the hydroxy ester product have been performed as a one-pot process. Extension of this work for the synthesis of various natural products containing *syn*-tetrahydropyran moiety will be published in due course.

In conclusion, stabilized Wittig ylides are found to be compatible with conditions of a $Pd(OH)_2$-catalyzed isomerization. This observation paved the way for the development of efficient domino processes in which the isomerization as an atom-economic carbon–carbon bond-forming process was employed as the key step to generate the aldehyde component of a succeeding Wittig olefination. This domino process is followed by a hydrogenation reaction of the acceptor substituted alkene. With the alkyl-substituted stabilized Wittig ylides, the domino process can be stopped at the olefin stage and can be hydrogenated after isolation to afford the saturated derivatives. Thus, depending on the reaction conditions, sequential isomerization–Wittig olefination and sequential isomerization–Wittig olefination–hydrogenation processes or sequential isomerization–Wittig olefination–oxa-Michael reaction could be realized. The present work opens a new and efficient one-pot synthetic route to chiral tetrahydropyran derivatives directly from allylic alcohols.

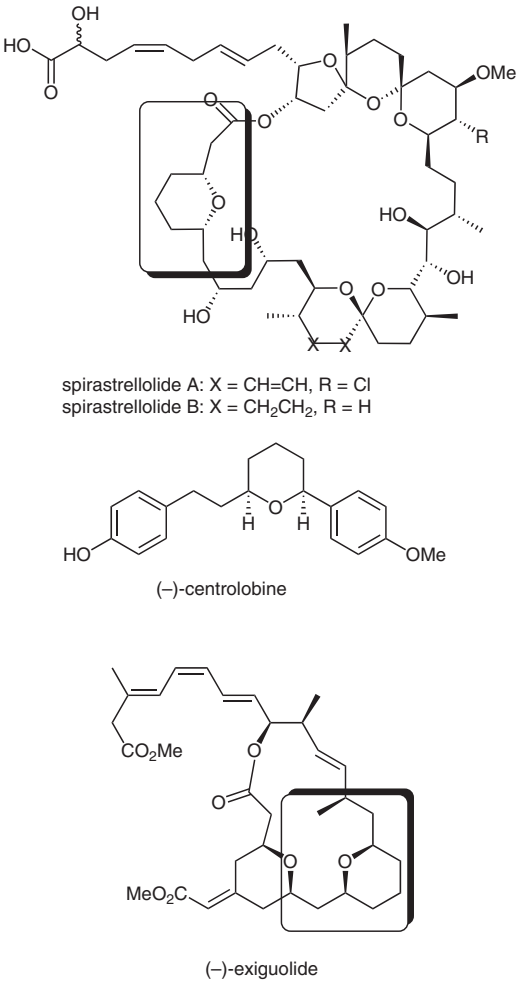


Figure 1 Natural products with 2,6-*syn*-tetrahydropyran rings

Unless otherwise mentioned, all reactions were carried out using standard syringe, septa, and cannula techniques. All glassware was flame- or oven-dried and cooled under an inert atmosphere of N_2 unless otherwise stated. Column chromatography was performed using silica gel (60–120 mesh) and the column was usually eluted with EtOAc–hexanes. The diastereomeric excesses of the products were measured by chiral-phase HPLC using Chiralpak AS column. Analytical TLC was performed on precoated silica gel-60 F254 (0.5 mm) glass plates. Visualization of the spots on TLC plates was achieved either by exposure to iodine vapor or UV light or by dipping the plates in H_2SO_4/β-naphthol or ethanolic anisaldehyde–H_2SO_4–AcOH or phosphomolybdic acid–H_2SO_4 solution and heating the plates at 120 °C. ^{1}H NMR spectra were recorded at 200, 300,

400, 500 MHz and ^{13}C NMR spectra were recorded at 50, 75 MHz in $CDCl_3$ using TMS as the reference standard. Standard abbreviations were used to denote multiplicities of the signals. IR spectra were recorded on PerkinElmer Infrared-683 spectrophotometer with NaCl optics. Spectra were calibrated against the polystyrene absorption at 1610 cm^{-1}. Samples were scanned neat. The optical rotations were measured on JASCO DIP-360 Digital Polarimeter. Mass spectra were recorded on Micro Mass VG-7070H mass spectrometer for ESI and EI are given in mass units (*m*/*z*). High-resolution mass spectra (HRMS) [ESI+] were obtained using either a TOF or a double focusing spectrometer.

Sequential One-Pot Isomerization–Wittig Olefination; General Procedure

A 50 mL two-necked round-bottomed flask was charged with $Pd(OH)_2/C$ (23 mg, 7 mol%) and benzene (3 mL). H_2 gas then was passed through the suspension via a balloon for 30 min (for the activation of the catalyst). The H_2 gas supply was stopped and strring continued for 10 min after which a solution of allylic alcohol **1** (0.5 mmol) in benzene (3 mL) was added. The reaction mixture was stirred for another 10 min. After complete conversion of allylic alcohol to the corresponding aldehyde, as indicated by TLC (eluent: EtOAc–hexane, 2:8), the required stable Wittig ylide (0.65 mmol) was added and the mixture stirred either at r.t. or at reflux conditions (see Table 1). After completion of the reaction, the mixture was filtered through a Celite pad and washed with EtOAc (10 mL). The filtrate was concentrated in vacuo and the residue was purified by silica gel column chromatography (2–30% EtOAc–hexane as eluent) to afford enoate/enone **6** (83–89%).

Sequential One-Pot Isomerization–Wittig Olefination–Hydrogenation; General Procedure

A 50 mL two-necked round-bottomed flask was charged with $Pd(OH)_2/C$ (23 mg, 7 mol%) and benzene (3 mL). H_2 gas was then passed through the suspension via a balloon for 30 min (for the activation of the catalyst). The H_2 gas supply was stopped and stirring continued for 10 min after which a solution of the respective allylic alcohol **1** (0.5 mmol) in benzene (3 mL) was added. The reaction mixture was stirred for another 10 min. After complete conversion of allylic alcohol to the corresponding aldehyde, as indicated by TLC (eluent: EtOAc–hexane, 2:8), the required stable Wittig ylide (0.65 mmol) was added and the mixture stirred either at r.t. or at reflux conditions (see Table 1). Then, the mixture was cooled to r.t., another portion of $Pd(OH)_2/C$ (7 mol%) was added under N_2 atmosphere and the mixture was stirred under H_2 atmosphere. After completion of the reaction, the mixture was filtered through a Celite pad a and washed with EtOAc (3 × 10 mL). The filtrate was concentrated in vacuo and the residue was purified by silica gel column chromatography (2–30% EtOAc–hexane as eluent) to afford product **7** (80–86%).

(*E*)-6-[(2*S*)-1,4-Dioxaspiro[4.5]dec-2-yl]-1-methylenehex-2-enyl Ethyl Ether (9a)

Yield: 120 mg (89%); colorless liquid; R_f = 0.6 (EtOAc–hexane, 2:8).

$[\alpha]_D^{28}$ –0.3 (*c* 1.5, $CHCl_3$).

IR (neat): 2936, 2862, 1720, 1655, 1448, 1366, 1278, 1198, 1163, 1106, 985, 928 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 6.94 (td, *J* = 6.9, 15.6 Hz, 1 H), 5.80 (td, *J* = 1.5, 15.6 Hz, 1 H), 4.16 (q, *J* = 6.9 Hz, 2 H), 4.10–3.97 (m, 2 H), 3.51–3.45 (m, 1 H), 2.43–2.21 (m, 2 H), 1.80–1.64 (m, 2 H), 1.63–1.50 (m, 8 H), 1.44–1.36 (m, 2 H), 1.29 (t, *J* = 6.9 Hz, 3 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 166.5, 148.1, 121.7, 109.5, 74.7, 68.8, 60.2, 36.6, 35.2, 32.2, 28.5, 25.2, 24.0, 23.9, 14.3.

HRMS (ESI): *m*/*z* calcd for $C_{15}H_{25}O_4$ (M + H)$^+$: 269.1752; found: 269.1766.

(*E*)-7-[(2*S*)-1,4-Dioxaspiro[4.5]dec-2-yl]hept-3-en-2-one (9b)

Yield: 105 mg (88%); colorless liquid; R_f = 0.3 (EtOAc–hexane, 2:8).

$[\alpha]_D^{28}$ –0.2 (*c* 1.4, $CHCl_3$).

IR (neat): 2934, 2860, 1676, 1628, 1448, 1364, 1280, 1253, 1163, 1104, 1041, 980, 928 cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 6.78 (td, *J* = 6.9, 15.8 Hz, 1 H), 6.07 (d, *J* = 15.8 Hz, 1 H), 4.08–3.97 (m, 2 H), 3.48 (t, *J* = 6.9 Hz, 1 H), 2.43–2.26 (m, 2 H), 2.21 (s, 3 H), 1.77–1.64 (m, 2 H), 1.63–1.50 (m, 10 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 198.5, 147.3, 131.4, 109.5, 74.7, 68.8, 36.6, 35.1, 32.2, 28.7, 26.8, 25.1, 24.0, 23.8.

HRMS (ESI): *m*/*z* calcd for $C_{14}H_{22}O_3$ + Na (M + Na)$^+$: 261.1466; found: 261.1479.

Ethyl (*E*)-6-[(4-Methoxybenzyl)oxy]hex-2-enoate (11a)

Yield: 119 mg (86%); yellow oil; R_f = 0.6 (EtOAc–hexane, 2:8).

IR (neat): 2937, 2857, 1717, 1654, 1613, 1586, 1513, 1464, 1367, 1302, 1247, 1173 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.19 (d, *J* = 8.5 Hz, 2 H), 6.91 (td, *J* = 7.0, 15.5 Hz, 1 H), 6.82 (d, *J* = 8.5 Hz, 2 H), 5.77 (td, *J* = 1.5, 15.5 Hz, 1 H), 4.39 (s, 2 H), 4.16 (q, *J* = 7.2 Hz, 2 H), 3.79 (s, 3 H), 3.42 (t, *J* = 6.0 Hz, 2 H), 2.29 (dq, *J* = 1.3, 7.2 Hz, 2 H), 1.79–1.69 (m, 2 H), 1.29 (t, *J* = 7.2 Hz, 3 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 166.5, 159.0, 148.5, 130.3, 129.1, 121.5, 113.6, 72.5, 68.8, 60.0, 55.1, 29.7, 28.0, 14.1.

HRMS (ESI): *m*/*z* calcd for $C_{16}H_{22}O_4$ + Na (M + Na)$^+$: 301.1415; found: 301.1429.

(*E*)-7-[(4-Methoxybenzyl)oxy]hept-3-en-2-one (11b)

Yield: 104 mg (84%); pale yellow oil; R_f = 0.3 (EtOAc–hexane, 2:8).

IR (neat): 2937, 2858, 1671, 1626, 1614, 1512, 1464, 1442, 1362, 1301, 1250, 1174, 1098, 1034, 979 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.19 (d, *J* = 8.5 Hz, 2 H), 6.82 (d, *J* = 8.5 Hz, 2 H), 6.73 (dt, *J* = 7.0, 16.0 Hz, 1 H), 6.02 (d, *J* = 16.0 Hz, 1 H), 4.39 (s, 2 H), 3.79 (s, 3 H), 3.42 (t, *J* = 6.0 Hz, 2 H), 2.31 (q, *J* = 7.2 Hz, 2 H), 2.18 (s, 3 H), 1.79–1.69 (m, 2 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 198.5, 158.9, 147.7, 131.2, 130.1, 129.0, 113.5, 72.3, 68.6, 54.9, 29.0, 27.9, 26.5.

HRMS (ESI): *m*/*z* calcd for $C_{15}H_{20}O_3$ + Na (M + Na)$^+$: 271.1310; found: 271.1301.

Ethyl (*E*)-6-[(4-Methoxybenzyl)oxy]-2-methylhex-2-enoate (11c)

Yield: 121 mg (83%); pale yellow oil; R_f = 0.7 (EtOAc–hexane, 2:8).

IR (neat): 2936, 2858, 1709, 1649, 1613, 1513, 1464, 1444, 1366, 1249, 1173, 1132, 1095, 1036 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.19 (d, *J* = 8.5 Hz, 2 H), 6.81 (d, *J* = 8.5 Hz, 2 H), 6.70 (t, *J* = 7.5 Hz, 1 H), 4.39 (s, 2 H), 4.16 (q, *J* = 7.2 Hz, 2 H), 3.79 (s, 3 H), 3.41 (t, *J* = 6.0 Hz, 2 H), 2.26 (q, *J* = 7.2 Hz, 2 H), 1.82 (s, 3 H), 1.72 (m, 2 H), 1.30 (t, *J* = 7.2 Hz, 3 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 168.0, 159.0, 141.4, 130.4, 129.1, 128.1, 113.6, 72.5, 69.1, 60.3, 55.1, 28.5, 25.3, 14.2, 12.2.

HRMS (ESI): *m*/*z* calcd for $C_{17}H_{24}O_4$ + Na (M + Na)$^+$: 315.1572; found: 315.1584.

Ethyl (*E*,6*S*)-6-[(4-Methoxybenzyl)oxy]hept-2-enoate (13a)
Yield: 130 mg (89%); colorless oil; R_f = 0.6 (EtOAc–hexane, 2:8).

$[\alpha]_D^{29}$ +29.0 (*c* 1.1, $CHCl_3$).

IR (neat): 2964, 2930, 1719, 1654, 1613, 1513, 1464, 1368, 1301, 1247, 1173, 1040 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.19 (d, *J* = 8.5 Hz, 2 H), 6.89 (td, *J* = 6.9, 15.5 Hz, 1 H), 6.81 (d, *J* = 8.5 Hz, 2 H), 5.73 (td, *J* = 1.3, 15.5 Hz, 1 H), 4.48 (d, *J* = 11.3 Hz, 1 H), 4.31 (d, *J* = 11.3 Hz, 1 H), 4.15 (q, *J* = 6.9 Hz, 2 H), 3.79 (s, 3 H), 3.53–3.42 (m, 1 H), 2.37–2.16 (m, 2 H), 1.75–1.50 (m, 2 H), 1.29 (t, *J* = 6.9 Hz, 3 H), 1.18 (d, *J* = 6.0 Hz, 3 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 166.6, 159.0, 148.9, 130.7, 129.2, 121.3, 113.7, 73.4, 70.0, 60.1, 55.2, 34.9, 28.2, 19.5, 14.2.

HRMS (ESI): *m*/*z* calcd for $C_{17}H_{24}O_4$ + Na $(M + Na)^+$: 315.1572; found: 315.1584.

(*E*,7*S*)-7-[(4-Methoxybenzyl)oxy]oct-3-en-2-one (13b)
Yield: 114 mg (87%); colorless oil; R_f = 0.4 (EtOAc–hexane, 2:8).

$[\alpha]_D^{29}$ +25.3 (*c* 1.1, $CHCl_3$).

IR (neat): 2930, 2857, 1673, 1613, 1513, 1460, 1361, 1301, 1248, 1173, 1030 cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 7.19 (d, *J* = 7.7 Hz, 2 H), 6.81 (d, *J* = 7.7 Hz, 2 H), 6.70 (td, *J* = 6.7, 15.5 Hz, 2 H), 5.97 (d, *J* = 15.5 Hz, 1 H), 4.49 (d, *J* = 10.6 Hz, 1 H), 4.29 (d, *J* = 10.6 Hz, 1 H), 3.79 (s, 3 H), 3.50–3.44 (m, 1 H), 2.36–2.21 (m, 2 H), 2.16 (s, 3 H), 1.72–1.64 (m, 1 H), 1.61–1.54 (m, 1 H), 1.19 (d, *J* = 6.7 Hz, 3 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 198.6, 159.1, 148.2, 131.2, 130.7, 129.2, 113.7, 73.3, 69.9, 55.2, 35.0, 28.5, 26.7, 19.4.

HRMS (ESI): *m*/*z* calcd for $C_{16}H_{22}O_3$ + Na $(M + Na)^+$: 285.1466; found: 285.1460.

Ethyl (*E*,6*S*)-6-[(4-Methoxybenzyl)oxy]-2-methylhept-2-enoate (13c)
Yield: 129 mg (84%); yellow oil; R_f = 0.7 (EtOAc–hexane, 2:8).

$[\alpha]_D^{29}$ +19.3 (*c* 1.3, $CHCl_3$).

IR (neat): 2969, 2932, 1708, 1648, 1613, 1513, 1460, 1368, 1247, 1202, 1172, 1134, 1089, 1036, 822 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.20 (d, *J* = 8.3 Hz, 2 H), 6.81 (d, *J* = 8.3 Hz, 2 H), 6.68 (t, *J* = 7.5 Hz, 1 H), 4.49 (d, *J* = 11.3 Hz, 1 H), 4.31 (d, *J* = 11.3 Hz, 1 H), 4.16 (q, *J* = 6.8 Hz, 2 H), 3.79 (s, 3 H), 3.53–3.42 (m, 1 H), 2.24 (q, *J* = 8.3 Hz, 2 H), 1.81 (s, 3 H), 1.74–1.50 (m, 2 H), 1.29 (t, *J* = 6.8 Hz, 3 H), 1.19 (d, *J* = 6.0 Hz, 3 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 168.1, 159.0, 141.8, 130.9, 129.1, 127.8, 113.7, 73.7, 70.0, 60.3, 55.2, 35.3, 24.7, 19.5, 14.2, 12.2.

HRMS (ESI): *m*/*z* calcd for $C_{18}H_{26}O_4$ + Na $(M + Na)^+$: 329.1728; found: 329.1744.

Ethyl (*E*)-7,8-Bis[1-(*tert*-butyl)-1,1-dimethylsilyl]oxynon-2-enoate (15a)
Yield: 189 mg (85%); yellow oil; R_f = 0.8 (EtOAc–hexane, 2:8).

$[\alpha]_D^{29}$ +1.4 (*c* 1.2, $CHCl_3$).

IR (neat): 2955, 2931, 2887, 2858, 1723, 1655, 1472, 1463, 1367, 1256, 1144, 1098, 1041, 982, 835 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 6.90 (td, *J* = 6.9, 15.5 Hz, 1 H), 5.76 (td, *J* = 1.5, 15.5 Hz, 1 H), 4.16 (q, *J* = 7.1 Hz, 2 H), 3.67–3.59 (m, 1 H), 3.49–3.44 (m, 1 H), 2.22–2.14 (m, 2 H), 1.64–1.37 (m, 4 H), 1.29 (t, *J* = 7.1 Hz, 3 H), 1.08 (d, *J* = 6.2 Hz, 3 H), 0.89 (s, 9 H), 0.88 (s, 9 H), 0.06 (s, 3 H), 0.04 (s, 9 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 166.6, 149.1, 121.4, 76.8, 71.4, 60.1, 33.1, 32.4, 26.0, 25.9, 23.4, 19.4, 18.2, 18.1, 14.3, –4.1, –4.2, –4.5, –4.7.

HRMS (ESI): *m*/*z* calcd for $C_{23}H_{48}O_4Si_2$ + Na $(M + Na)^+$: 467.2988; found: 467.2991.

(*E*)-8,9-Bis[1-(*tert*-butyl)-1,1-dimethylsilyl]oxydec-3-en-2-one (15b)
Yield: 172 mg (83%); yellow oil; R_f = 0.6 (EtOAc–hexane, 2:8).

$[\alpha]_D^{29}$ +3.7 (*c* 1.0, $CHCl_3$).

IR (neat): 2932, 2891, 2858, 1678, 1630, 1466, 1362, 1253, 1100, 1035, 834 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 6.73 (td, *J* = 6.8, 15.8 Hz, 1 H), 6.03 (td, *J* = 1.5, 15.8 Hz, 1 H), 3.67–3.59 (m, 1 H), 3.49–3.44 (m, 1 H), 2.25–2.16 (m, 5 H), 1.62–1.48 (m, 2 H), 1.46–1.36 (m, 2 H), 1.08 (d, *J* = 6.0 Hz, 3 H), 0.89 (s, 9 H), 0.88 (s, 9 H), 0.06 (s, 3 H), 0.05 (s, 3 H), 0.04 (s, 6 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 198.5, 148.2, 131.4, 76.8, 71.4, 33.1, 32.7, 26.8, 26.0, 25.9, 23.4, 19.5, 18.2, 18.1, –4.1, –4.2, –4.4, –4.7.

HRMS (ESI): *m*/*z* calcd for $C_{22}H_{46}O_3Si_2$ + Na $(M + Na)^+$: 437.2878; found: 437.2866.

(5*S*,6*S*,*E*)-9-(Benzyloxy)-6-(*tert*-butyldimethylsilyloxy)-5-methylnon-3-en-2-one (17b)
Yield: 172 mg (82%); colorless oil; R_f = 0.6 (EtOAc–hexane, 2:8).

$[\alpha]_D^{28}$ –9.0 (*c* 1.2, $CHCl_3$).

IR (neat): 2937, 2857, 1677, 1628, 1459, 1362, 1253, 1097, 835, 773 cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 7.33–7.22 (m, 5 H), 6.72 (td, *J* = 6.9, 15.8 Hz, 1 H), 6.03 (d, *J* = 15.8 Hz, 1 H), 4.47 (s, 2 H), 3.57–3.53 (m, 1 H), 3.45–3.40 (m, 2 H), 2.31–2.23 (m, 1 H), 2.20 (s, 3 H), 2.19–2.11 (m, 1 H), 1.70–1.60 (m, 2 H), 1.58–1.47 (m, 3 H), 1.46–1.38 (m, 2 H), 0.89 (s, 9 H), 0.85 (d, *J* = 6.9 Hz, 3 H), 0.03 (s, 3 H), 0.02 (s, 3 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 198.7, 148.6, 138.5, 131.2, 128.3, 127.5, 127.4, 75.4, 72.8, 70.4, 37.6, 30.6, 30.4, 29.5, 26.7, 26.3, 25.8, 18.1, 14.5, –4.3, –4.4.

HRMS (ESI): *m*/*z* calcd for $C_{25}H_{42}O_3Si$ + Na $(M + Na)^+$: 441.2800; found: 441.2782.

(*S*,*E*)-Ethyl 6-(Methyloxymethoxy)-6-phenylhex-2-enoate (19a)
Yield: 122 mg (88%); yellow oil; R_f = 0.6 (EtOAc–hexane, 2:8).

$[\alpha]_D^{28}$ –130.1 (*c* 1.3, $CHCl_3$).

IR (neat): 2937, 1719, 1653, 1451, 1367, 1270, 1152, 1035, 703 cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 7.33–7.22 (m, 5 H), 6.92 (td, *J* = 6.9, 15.8 Hz, 1 H), 5.78 (d, *J* = 15.8 Hz, 1 H), 4.55 (t, *J* = 5.9 Hz, 1 H), 4.47 (s, 2 H), 4.15 (q, *J* = 6.9 Hz, 2 H), 3.33 (s, 3 H), 2.36–2.28 (m, 1 H), 2.27–2.18 (m, 1 H), 2.02–1.93 (m, 1 H), 1.85–1.77 (m, 1 H), 1.28 (t, *J* = 6.9 Hz, 3 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 166.5, 148.3, 141.3, 128.4, 127.7, 126.7, 121.6, 94.0, 77.1, 60.1, 55.6, 36.0, 28.4, 14.1.

HRMS (ESI): *m*/*z* calcd for $C_{16}H_{22}O_4$ + Na $(M + Na)^+$: 301.1415; found: 301.1409.

Ethyl (*E*)-6-Phenoxyhex-2-enoate (21a)
Yield: 94 mg (86%); yellow oil; R_f = 0.5 (EtOAc–hexane, 2:8).

IR (neat): 2939, 1718, 1654, 1595, 1494, 1243, 1169, 1042, 754 cm^{-1}.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.26–7.19 (m, 2 H), 7.02–6.80 (m, 4 H), 5.82 (d, *J* = 15.8 Hz, 1 H), 4.17 (q, *J* = 7.5 Hz, 2 H), 3.96 (t, *J* = 6.0 Hz, 2 H), 2.46–2.37 (m, 2 H), 2.02–1.90 (m, 2 H), 1.29 (t, *J* = 7.5 Hz, 3 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 166.5, 158.7, 148.0, 129.3, 121.9, 120.6, 114.4, 66.6, 60.1, 28.7, 27.7, 14.2.

HRMS (ESI): *m*/*z* calcd for $C_{14}H_{18}O_3$ + Na (M + Na)$^+$: 257.1153; found: 257.1159.

(2*S*)-2-(6-Ethoxyhept-6-enyl)-1,4-dioxaspiro[4.5]decane (22a)
Yield: 117 mg (86%); colorless liquid; R_f = 0.7 (EtOAc–hexane, 2:8).

$[\alpha]_D^{29}$ +4.8 (*c* 0.9, $CHCl_3$).

IR (neat): 2936, 2862, 1722, 1655, 1448, 1366, 1279, 1163, 1105, 1041, 985, 929 cm^{-1}.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 4.10 (q, *J* = 7.2 Hz, 2 H), 4.05–3.94 (m, 2 H), 3.48–3.41 (m, 1 H), 2.28 (t, *J* = 7.2 Hz, 2 H), 1.71–1.31 (m, 16 H), 1.26 (t, *J* = 7.2 Hz, 3 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 173.5, 109.1, 75.3, 69.0, 60.2, 36.5, 35.2, 34.1, 33.4, 25.3, 25.1, 24.8, 23.9, 23.8, 14.1.

HRMS (ESI): *m*/*z* calcd for $C_{15}H_{27}O_4$ (M + H)$^+$: 271.1909; found: 271.1916.

7-[(2*S*)-1,4-Dioxaspiro[4.5]dec-2-yl]heptan-2-one (22b)
Yield: 104 mg (86%); colorless liquid; R_f = 0.5 (EtOAc–hexane, 2:8).

$[\alpha]_D^{29}$ +4.76 (*c* 1.1, $CHCl_3$).

IR (neat): 2935, 2859, 1715, 1450, 1363, 1279, 1163, 1106, 1039, 932 cm^{-1}.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 4.07–3.94 (m, 2 H), 3.43 (t, *J* = 6.8 Hz, 1 H), 2.42 (t, *J* = 7.2 Hz, 2 H), 2.11 (s, 3 H), 1.64–1.24 (m, 16 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 208.8, 109.2, 75.4, 69.0, 43.5, 36.6, 35.2, 33.5, 29.8, 25.4, 25.2, 24.0, 23.9, 23.7.

HRMS (ESI): *m*/*z* calcd for $C_{14}H_{24}O_3$ + Na (M + Na)$^+$: 263.1618; found: 263.1589.

Ethyl 6-[(4-Methoxybenzyl)oxy]hexanoate (23a)
Yield: 118 mg (84%); colorless oil; R_f = 0.6 (EtOAc–hexane, 2:8).

IR (neat): 2937, 2860, 1733, 1612, 1513, 1460, 1369, 1247, 1174, 1097, 1035, 820 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.19 (d, *J* = 8.6 Hz, 2 H), 6.81 (d, *J* = 8.6 Hz, 2 H), 4.38 (s, 2 H), 4.09 (q, *J* = 6.7 Hz, 2 H), 3.78 (s, 3 H), 3.39 (t, *J* = 6.7 Hz, 2 H), 2.26 (t, *J* = 6.7 Hz, 2 H), 1.66–1.56 (m, 4 H), 1.43–1.36 (m, 2 H), 1.25 (t, *J* = 6.7 Hz, 3 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 173.5, 158.9, 130.5, 128.9, 113.5, 72.3, 69.6, 59.9, 54.9, 34.0, 29.2, 25.5, 24.5, 14.0.

HRMS (ESI): *m*/*z* calcd for $C_{16}H_{24}O_4$ + Na (M + Na)$^+$: 303.1572; found: 303.1563.

7-[(4-Methoxybenzyl)oxy]heptan-2-one (23b)
Yield: 104 mg (83%); pale yellow oil; R_f = 0.4 (EtOAc–hexane, 2:8).

IR (neat): 2936, 2859, 1715, 1613, 1513, 1463, 1361, 1301, 1247, 1172, 1098, 1035, 821 cm^{-1}.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.19 (d, *J* = 8.3 Hz, 2 H), 6.81 (d, *J* = 8.3 Hz, 2 H), 4.38 (s, 2 H), 3.78 (s, 3 H), 3.39 (t, *J* = 6.8 Hz, 2 H), 2.39 (t, *J* = 6.8 Hz, 2 H), 2.09 (s, 3 H), 1.63–1.50 (m, 5 H), 1.40–1.30 (m, 3 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 208.9, 159.0, 130.6, 129.1, 113.6, 72.4, 64.7, 55.1, 43.5, 29.7, 29.4, 25.7, 23.5.

HRMS (ESI): *m*/*z* calcd for $C_{15}H_{22}O_3$ + Na (M + Na)$^+$: 273.1466; found: 273.1478.

Ethyl 6-[(4-Methoxybenzyl)oxy]-2-methylhexanoate (23c)
Yield: 124 mg (84%); yellow oil; R_f = 0.7 (EtOAc–hexane, 2:8).

IR (neat): 2937, 2859, 1731, 1613, 1513, 1461, 1371, 1248, 1174, 1096, 1035, 820 cm^{-1}.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.19 (d, *J* = 8.6 Hz, 2 H), 6.81 (d, *J* = 8.6 Hz, 2 H), 4.38 (s, 2 H), 4.10 (q, *J* = 7.1 Hz, 2 H), 3.78 (s, 3 H), 3.38 (t, *J* = 6.4 Hz, 2 H), 2.43–2.32 (m, 1 H), 1.71–1.52 (m, 4 H), 1.48–1.30 (m, 4 H), 1.25 (t, *J* = 7.1 Hz, 3 H), 1.13 (d, *J* = 6.9 Hz, 3 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 176.7, 159.0, 130.6, 129.1, 113.7, 72.4, 69.7, 60.0, 55.2, 39.4, 33.5, 29.5, 23.8, 17.0, 14.2.

HRMS (ESI): *m*/*z* calcd for $C_{17}H_{26}O_4$ + Na (M + Na)$^+$: 317.1728; found: 317.1709.

(7*S*)-7-[(4-Methoxybenzyl)oxy]octan-2-one (24b)
Yield: 112 mg (85%); colorless oil; R_f = 0.5 (EtOAc–hexane, 2:8).

$[\alpha]_D^{29}$ +17.6 (*c* 1.1, $CHCl_3$).

IR (neat): 2933, 2861, 1713, 1613, 1513, 1459, 1367, 1300, 1246, 1171, 1069, 1036, 821 cm^{-1}.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.19 (d, *J* = 8.3 Hz, 2 H), 6.81 (d, *J* = 8.3 Hz, 2 H), 4.46 (d, *J* = 11.3 Hz, 1 H), 4.31 (d, *J* = 11.3 Hz, 1 H), 3.78 (s, 3 H), 3.49–3.39 (m, 1 H), 2.37 (t, *J* = 7.5 Hz, 2 H), 2.10 (s, 3 H), 1.57–1.24 (m, 6 H), 1.15 (d, *J* = 6.0 Hz, 3 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 209.2, 158.9, 131.0, 129.1, 113.6, 74.1, 69.9, 55.2, 43.6, 36.3, 29.8, 25.0, 23.7, 19.5.

HRMS (ESI): *m*/*z* calcd for $C_{16}H_{24}O_3$ + Na (M + Na)$^+$: 287.1623; found: 287.1634.

Ethyl (6*S*)-6-[(4-Methoxybenzyl)oxy]-2-methylheptanoate (24c)
Yield: 125 mg (81%); colorless oil; R_f = 0.7 (EtOAc–hexane, 2:8).

$[\alpha]_D^{29}$ +14.0 (*c* 1.0, $CHCl_3$).

IR (neat): 2971, 2936, 2864, 1731, 1613, 1513, 1460, 1374, 1247, 1175, 1036, 819 cm^{-1}.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.19 (d, *J* = 8.3 Hz, 2 H), 6.80 (d, *J* = 8.3 Hz, 2 H), 4.46 (d, *J* = 11.3 Hz, 1 H), 4.33 (d, *J* = 11.3 Hz, 1 H), 4.10 (q, *J* = 6.8 Hz, 2 H), 3.78 (s, 3 H), 3.50–3.39 (m, 1 H), 2.41– 2.30 (m, 1 H), 1.65–1.31 (m, 6 H), 1.25 (t, *J* = 6.8 Hz, 3 H), 1.16–1.10 (m, 6 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 176.7, 159.0, 131.1, 129.1, 113.6, 74.2, 69.9, 60.0, 55.2, 39.4, 36.4, 33.7, 23.2, 19.5, 17.0, 14.2.

HRMS (ESI): *m*/*z* calcd for $C_{18}H_{29}O_4$ (M + H)$^+$: 309.2065; found: 309.1911.

8,9-Bis[1-(*tert*-butyl)-1,1-dimethylsilyl]oxydecan-2-one (25b)
Yield: 166 mg (80%); colorless oil; R_f = 0.8 (EtOAc–hexane, 2:8).

$[\alpha]_D^{29}$ +1.1 (*c* 1.4, $CHCl_3$).

IR (neat): 2932, 2891, 2857, 1719, 1466, 1362, 1253, 1105, 1038, 834 cm^{-1}.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.67–3.58 (m, 1 H), 3.48–3.42 (m, 1 H), 2.39 (t, *J* = 7.5 Hz, 2 H), 2.10 (s, 3 H), 1.61–1.50 (m, 2 H), 1.40–1.23 (m, 6 H), 1.06 (d, *J* = 6.0 Hz, 3 H), 0.88 (s, 18 H), 0.05 (s, 3 H), 0.04 (s, 9 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 209.0, 77.1, 71.5, 43.7, 33.6, 29.8, 29.5, 26.0, 25.9, 24.8, 23.8, 19.1, 18.2, 18.1, –4.1, –4.3, –4.5, –4.7.

HRMS (ESI): *m*/*z* calcd for $C_{22}H_{48}O_3Si_2$ + Na $(M + Na)^+$: 439.3040; found: 439.3040.

Ethyl (*S*)-6-(Methoxymethoxy)-6-phenylhexanoate (26a)
Yield: 112 mg (80%); yellow oil; R_f = 0.5 (EtOAc–hexane, 2:8).

$[\alpha]_D^{28}$ –114.0 (*c* 1.5, $CHCl_3$).

IR (neat): 2939, 1735, 1455, 1372, 1149, 1098, 1034, 918, 760, 702 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.32–7.18 (m, 5 H), 4.51 (dd, *J* = 5.2, 7.5 Hz, 1 H), 4.45 (s, 2 H), 4.08 (q, *J* = 6.8 Hz, 2 H), 3.32 (s, 3 H), 2.25 (t, *J* = 7.5 Hz, 2 H), 1.90–1.76 (m, 1 H), 1.72–1.58 (m, 3 H), 1.53–1.40 (m, 1 H), 1.38–1.27 (m, 1 H), 1.23 (t, *J* = 6.8 Hz, 3 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 173.6, 149.9, 128.3, 127.5, 126.8, 94.0, 77.7, 60.1, 55.4, 37.5, 34.1, 25.4, 24.8, 14.2.

HRMS (ESI): *m*/*z* calcd for $C_{16}H_{24}O_4$ + Na $(M + Na)^+$: 303.1572; found: 303.1570.

Sequential One-Pot Isomerization–Wittig Olefination–Oxa-Michael Reaction; Ethyl 2-{(2*R*,6*S*)-6-[(4-Methoxybenzyl)oxy]methyltetrahydro-2*H*-2-pyranyl}acetate (30); Typical Procedure
A 50 mL two-necked round-bottomed flask was charged with $Pd(OH)_2$/C (23 mg, 7 mol%) and benzene (3 mL). H_2 gas was then passed through the suspension via a balloon for 30 min (for the activation of the catalyst). The H_2 gas supply was stopped and stirring continued for 10 min after which a solution of the allylic alcohol **27** (0.5 mmol) in benzene (3 mL) was added. The reaction mixture was stirred for another 10 min. After complete conversion of allylic alcohol to the corresponding lactol, as indicated by TLC (eluent: EtOAc–hexane, 3:7), the stable Wittig ylide **3** (0.65 mmol) was added and stirred at reflux conditions for 1 h. Then, the reaction mixture was allowed to attain r.t. and treated with 1 M solution of TBAF in THF (4.0 mmol) and the stirring was continued for 6 h. The mixture was filtered through a Celite pad and washed with EtOAc (3 × 10 mL). The filtrate was concentrated in vacuo and the residue was purified by silica gel column chromatography (15% EtOAc–hexane as eluent) to afford tetrahydropyran **30** as a colorless oil; yield: 124 mg (77%, over three steps); R_f = 0.6 (EtOAc–hexane, 3:7); $[\alpha]_D^{29}$ –5.1 (*c* 0.5, $CHCl_3$).

IR (neat): 2932, 2858, 1736, 1613, 1513, 1455, 1374, 1247, 1190, 1096, 1036, 820 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.19 (d, *J* = 8.5 Hz, 2 H), 6.80 (d, *J* = 8.5 Hz, 2 H), 4.44 (ABq, *J* = 11.7 Hz, 2 H), 4.10 (q, *J* = 7.2 Hz, 2 H), 3.78 (s, 3 H), 3.76–3.70 (m, 1 H), 3.59–3.50 (m, 1 H), 3.41 (dd, *J* = 5.6, 10.0 Hz, 1 H), 3.31 (dd, *J* = 4.9, 10.0 Hz, 1 H), 2.54 (dd, *J* = 7.1, 15.1 Hz, 1 H), 2.33 (dd, *J* = 6.0, 15.1 Hz, 1 H), 1.90–1.81 (m, 1 H), 1.68–1.50 (m, 3 H), 1.29–1.18 (m, 5 H).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = 171.3, 159.0, 130.4, 129.2, 113.6, 77.2, 74.3, 73.0, 72.8, 60.3, 55.2, 41.6, 31.0, 27.7, 22.9, 14.1.

HRMS (ESI): *m*/*z* calcd for $C_{18}H_{26}O_5$ + Na $(M + Na)^+$: 345.1677; found: 345.1683.

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References

(1) (a) *Organic Syntheses via Metal Carbonyls*; Wender, I.; Pino, P., Eds.; Wiley: New York, **1977**. (b) *New Syntheses with Carbon Monoxide*; Falbe, J., Ed.; Springer: Berlin, **1980**, 1–225. (c) Kohlpaintner, C. W.; Frohning, C. D. In *Applied Homogeneous Catalysis with Organometallic Compounds*, Vol. 1; Cornils, B.; Herrmann, W. A., Eds.; VCH: Weinheim, **1996**, 1–39.
(2) Gold, H. In *Houben–Weyl Methoden der Organischen Chemie*, Vol. 7/2b; Müller, E., Ed.; Thieme: Stuttgart, **1976**, 1930–1931.
(3) Bayer, O. In *Houben–Weyl Methoden der Organischen Chemie*, Vol. 7/1; Müller, E., Ed.; Thieme: Stuttgart, **1954**, 413.
(4) Sauer, J. C. *Org. Synth. Coll. Vol. 4*; Wiley: New York, **1963**, 813.
(5) *Handbook of Sol-Gel Science and Technology*, Vol. 3; Blum, J.; Avnir, D.; Sakka, S., Eds.; Kluwer: Boston, **2005**, 507–526; and references cited therein.
(6) Hamza, K.; Abu-Reziq, R.; Avnir, D.; Blum, J. *Org. Lett.* **2004**, *6*, 925.
(7) Levin, Y.; Hamza, K.; Abu-Reziq, R.; Blum, J. *Eur. J. Org. Chem.* **2006**, 1396.
(8) Sabitha, G.; Nayak, S.; Bhikshapathi, M.; Yadav, J. S. *Org. Lett.* **2011**, *13*, 382.
(9) (a) William, D. E.; Lapawa, M.; Feng, X.; Tarling, T.; Roberge, M.; Andersen, R. *Org. Lett.* **2004**, *6*, 2607. (b) Warabi, K.; Williams, D. E.; Patrick, B. O.; Roberge, M.; Andersen, R. J. *J. Am. Chem. Soc.* **2007**, *129*, 508.
(10) Aragao Craveiro, A.; da Costa Prado, A.; Gottlieb, O. R.; Welerson de Albuquerque, P. C. *Phytochemistry* **1970**, *9*, 1869.
(11) Ohta, S.; Uy, M. M.; Yanai, M.; Ohta, E.; Hirata, T.; Ikegami, S. *Tetrahedron Lett.* **2006**, *47*, 1957.
(12) (a) Haustedt, L. O.; Hartung, I. V.; Hoffmann, H. M. R. *Angew. Chem. Int. Ed.* **2003**, *42*, 2711. (b) Marmsäter, F. P.; West, F. G. *Chem. Eur. J.* **2002**, *8*, 4346. (c) Hale, K. J.; Hummersone, M. G.; Manaviazar, S.; Frigerio, M. *Nat. Prod. Rep.* **2002**, *19*, 413.
(13) Sabitha, G.; Reddy, D. V.; Rao, A. S.; Yadav, J. S. *Tetrahedron Lett.* **2010**, *51*, 4195.