Stereoselective Intramolecular Cyclization of β-Alkoxycarbonyl-ω-formylallylsilanes into Bicyclic α-Methylene-γ-lactones[1)]

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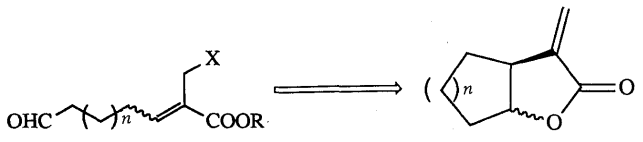
α-Methylene-γ-lactones fused to five- and six-membered carbocycles were efficiently synthesized from β-ethoxycarbonyl-ω-formylallylsilane derivatives by means of the intramolecular Hosomi reaction. The formylated allylsilanes (11a, b, 12a and b) were synthesized from ethyl β-trimethylsilylpropionate and ω-tetrahydropyranyloxy-pentanal (4a) and -hexanal (4b) in several steps. The cyclization reaction of these aldehydes was performed under mild conditions with a high degree of stereocontrol. Treatment of the (*E*)- and (*Z*)-isomers of the allylsilanes (11a and 12a) with titanium tetrachloride or boron trifluoride etherate gave a five-membered *cis*-hydroxy ester (13a). Treatment of the (*Z*)-allylsilane derivative (11b) with titanium tetrachloride afforded a six-membered *cis*-hydroxy ester (13b) as a major product together with the *trans*-isomer (14b), and treatment with boron trifluoride etherate selectively gave the *cis*-isomer (13b). On the other hand, treatment of (*E*)-allylsilane (12b) with titanium tetrachloride selectively gave the *cis*-hydroxy ester (13b), while the use of boron trifluoride etherate exclusively afforded the *trans*-isomer (14b). These stereoselectivities can be explained in terms of chelated transition models. Lactonization of these hydroxy esters afforded the corresponding fused α-methylene-γ-lactones (16a, 17a and b) in good yields.

Keywords α-methylene-γ-lactone; allylsilane; intramolecular cyclization; Hosomi reaction; Lewis acid; stereoselectivity

The α-methylene-γ-lactone unit can be seen as a partial structure in a number of natural products, especially the mono-,[2a)] sesqui-[2b)] and diterpenes.[2c)] Many of these natural products have the lactone moiety *cis*- or *trans*-fused to a six-, seven-, ten- or fourteen-membered ring. Some of these terpenoid lactones exhibit interesting biological activities,[3)] such as cytotoxic, antitumoral, and bactericidal properties. A variety of strategies for the synthesis of the α-methylene-γ-lactone moiety has been reported.[4)] Many methods for the synthesis of this moiety, bicyclic α-methylene-γ-lactone, involve introduction of the lactone into a preformed carbocyclic framework. A one-step synthesis of bicyclic α-methylene-γ-lactones by an intramolecular cyclization of acyclic compounds was performed by Semmelhack and Wu[5)] and Okuda *et al.*[6)] They synthesized α-methylene-γ-lactones fused to six- or seven-membered carbocycles from ω-formyl-β-alkoxycarbonylallylhalides (Ia) by using zinc dust or chromium(II) reagent. We have reported the application of this method to the synthesis of α-methylene-γ-lactones fused to eight-, twelve-, or fourteen-membered carbocycles.[7)] The yield of this cyclization reaction was not satisfactory and sometimes varied depending on the quality of the chromium(II) reagent used. The stereochemistry of the cyclization reaction could not be controlled.

We planned to use the allylsilane derivatives (Ib) instead of the allylhalides (Ia). We have already used this method, the intramolecular Hosomi reaction, for the synthesis of α-methylene-γ-lactones fused to five- or six-membered carbocycles,[8)] and applied it to the synthesis of chiral lactones.[9,10)] Kuroda *et al.*[11)] also reported the synthesis of the α-methylene-γ-lactones, fused to a decaline ring, from ω-dimethoxy allylsilane derivatives. Now, we would like to report the details of the stereochemically controlled cyclization reaction of ω-formylated allylsilanes (**11** and **12**), affording the fused *cis*- and *trans*-α-methylene-γ-lactones (**16** and **17**).



Ia: X=Br
Ib: X=SiMe$_3$

II

Chart 1

Results and Discussion

Synthesis of (*E*)- and (*Z*)-ω-Formyl-β-ethoxycarbonylallyltrimethylsilanes ω-(Tetrahydropyranyloxy)alcohols (**2a—e**) derived from the corresponding diols (**1a—e**)[12)] were converted into the aldehydes (**4a—e**) by Swern oxidation.[13)] Reaction of the enolate of ethyl β-(trimethylsilyl)-propionate with the aldehydes (**4a—e**) by using lithium diisopropylamide (LDA) in tetrahydrofuran (THF) at −78 °C gave diastereomeric mixtures of the hydroxy esters (**5a—e**) in good yields. Methanesulfonylation of the hydroxy esters gave the corresponding mesylates (**6a—e**), which were treated with 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) in refluxing benzene to afford the (*Z*)-allylsilanes (**7a—e**) in fairly good yields. Removal of the protecting group of **7a—e** followed by Swern oxidation gave the aldehydes (**11a—e**) in good yields. The geometry of the double bond of the unsaturated esters (**11a—e**) was deduced to be *Z* from their ^{1}H-NMR spectra,[11,14)] which exhibited triplet signals due to the olefinic protons around δ 6.6 with the coupling constant of 7 Hz. The other isomers of the unsaturated esters, (*E*)-isomers (**12a** and **b**), were synthesized by using the Horner–Emmons reaction.[15)] The aldehydes (**4a** and **b**) were treated with the ylide derived from triethylphosphonoacetate, iodomethyltrimethylsilane and sodium hydride in dimethoxyethane (DME) in a one-pot procedure,[11,16)] to give mixtures of the (*Z*)- and (*E*)-allylsilane derivatives (**7a** and **8a**) and (**7b** and **8b**) in 44.5% and 46.3% yields, respectively. Removal of the

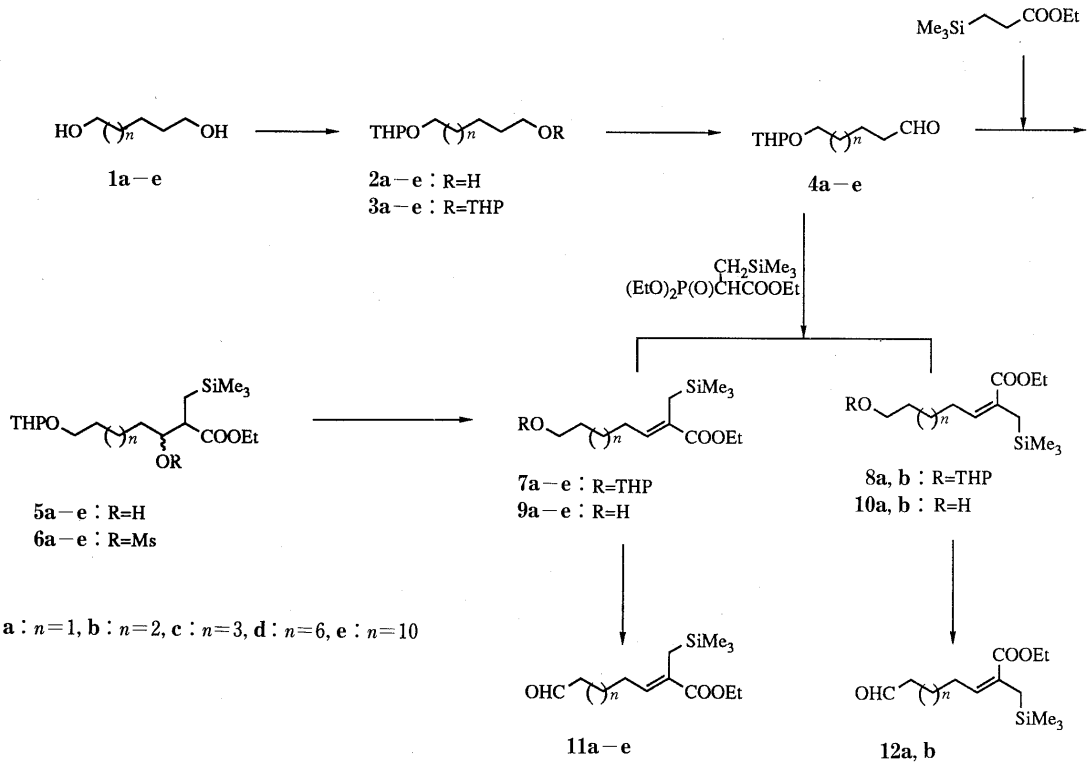


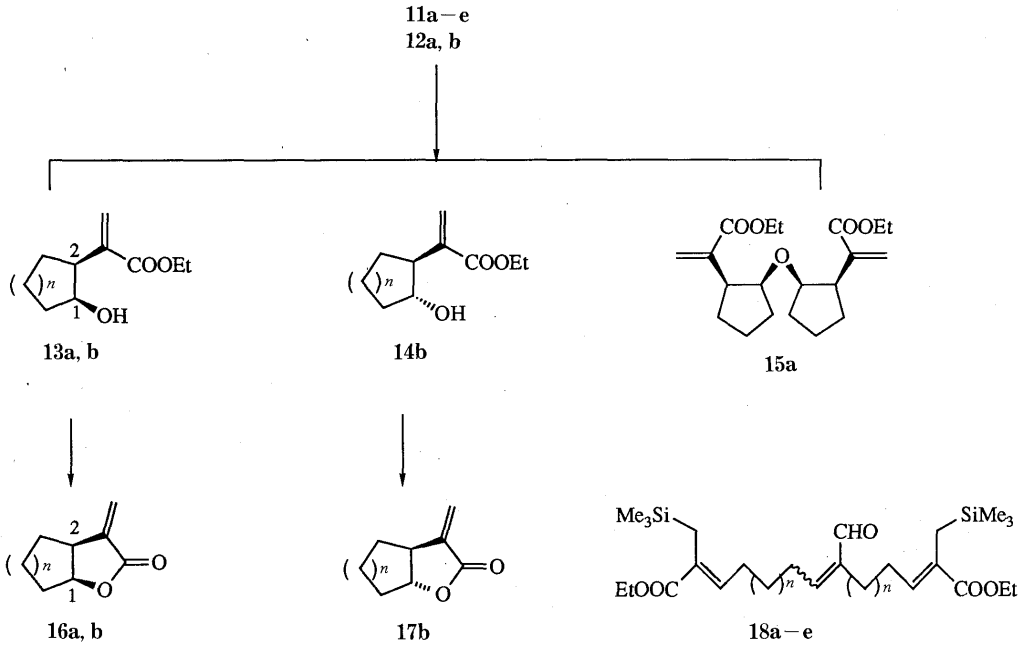
Chart 2

protecting group followed by Swern oxidation of the mixtures, (**7a** and **8a**) and (**7b** and **8b**), afforded 3 : 1 mixtures of the (*Z*)- and (*E*)-allylsilanes, (**11a** and **12a**) and (**11b** and **12b**), respectively. Separation of the geometric isomers was performed by medium pressure liquid chromatography (MPLC). The geometry of the double bonds of these isomers was determined from the ^{1}H-NMR spectra,[11,14] in which the vinyl proton signals of **12a** and **12b**, (*E*)-isomers, were observed at a higher field (δ 5.67) than those of the (*Z*)-isomers, **11a** and **b** (δ 6.61).

Intramolecular Cyclization of the ω-Formylallylsilanes The Lewis acid-catalyzed addition of allylsilanes to carbonyl compounds is well known as the Hosomi reaction,[17a–g] and usually proceeds under mild conditions with a high degree of stereocontrol. Intramolecular Hosomi reaction is frequently applied to the synthesis of cycloalkanols.[18a–f] Hosomi *et al.*[19] reported that the addition of β-(alkoxycarbonyl)allyltrimethylsilanes to aldehydes enables direct preparation of simple α-methylene-γ-lactones, though the yield is poor (about 25%) because of polymerization or aldol condensation of the aldehyde or products. In addition, the intermolecular reaction of *N*-monosubstituted 2-[(trimethylsilyl)methyl]propenamide with aldehyde gave the adducts, γ-hydroxy amide, in moderate to poor yields.[20] We believe, however, that the intramolecular modifications of the above reactions have several advantages over the intermolecular ones, and the application of this strategy to an intramolecular reaction could be a useful tool for the synthesis of bicyclic α-methylene-γ-lactone derivatives.

Reactivity of the Allylsilanes The first study compared the reactivities of the formylallylsilanes with various lengths of the carbon chain. The allylsilanes (**11a**, **b**, **12a** and **b**) were readily cyclized to the hydroxy esters (**13** and **14**) and/or lactone (**16**) fused to five- and six-membered carbocycles with boron trifluoride etherate, trimethylsilyl triflate and especially titanium tetrachloride. However, trifluoroacetic acid, ethylaluminum dichloride and tetrabutylammonium fluoride were ineffective for the cyclization reactions. On the other hand, the allylsilanes (**11c**, **d** and **e**) failed to undergo intramolecular cyclization reaction to seven-, ten- and fourteen-membered carbocycles with any of the reagents described above, but instead underwent intermolecular reaction, giving only dimeric aldehydes (**18c**, **d** and **e**) even at 0.001 M concentration, as shown in Table III. Each of the dimeric aldehydes (**18a**—**e**) was obtained as a single stereoisomer. These products were assigned to be the aldol condensation products from their ^{1}H-NMR spectra, which exhibited a singlet signal due to aldehyde proton at δ 9.3—9.4 and multiplet signals due to three olefinic protons around δ 6.5. The geometry of the α,β-unsaturated aldehyde moiety of **18** has not been determined yet. The results of these cyclization reactions are summarized in Tables I, II and III. This method can be effectively applied to the synthesis of five- and six-membered carbocycles, but not to larger rings.

Stereochemical Course of the Cyclization Reactions; Into Five-Membered Carbocycles The stereochemical course of the cyclization reaction has been shown to depend on the nature of the Lewis acid and the geometry of the allylsilanes. Cyclization reaction of both (*Z*)-allylsilane (**11a**) and (*E*)-isomer (**12a**) with titanium tetrachloride at a low temperature in dichloromethane afforded a single hydroxy ester (**13a**) in excellent yields (Table I). Treatment of the allylsilanes (**11a** and **12a**) with boron trifluoride etherate gave moderate yields of the same hydroxy ester (**13a**) together with a small amount of a dimeric ether (**15a**) expected to be derived from **13a** by dehydration



a : n=1, b : n=2, c : n=3, d : n=6, e : n=10

Chart 3

TABLE I. Intramolecular Cyclization of the Allylsilanes (**11a** and **12a**)

Entry	Substrate	Reagent	eq	Reaction conditions[a,b]		Products yield (%)					Conv. to **13**, **16** (%)	Ratio *cis*/*trans*
				Temp. (°C)	Time (h)	**13a**	**16a**	**15a**	**18a**	S.M.		
1	**11a**	$TiCl_4$	0.2	−10	1.0	No reaction						
2			1.1	−10	3.5	89	0	0	0	0	89	100/0
3			2.2	−50	3.0	59	0	0	0	5	63	100/0
4			2.2	−10	0.3	83	0	0	0	0	83	100/0
5			5.0	−10	0.3[c]	99	0	0	0	0	99	100/0
6		BF_3–OEt_2	1.1	−20—0	5.0	0	23	16	0	4	24	100/0
7			2.2	−20—0	5.0	0	27	10	0	0	27	100/0
8		Me_3SiOTf	0.1	r.t.	40.0	Trace						
9			1.1	r.t.	40.0	21	19	24	4	0	40	100/0
10		CF_3CO_2H	2.2	40	4.0	No reaction						
11		Bu_4NF	0.1	r.t.	3.0	No reaction						
12			0.1	r.t.—70	10.0	Complex mixture			59	0		
13			1.1	−60	3.0	0	0	0	57	0	0	
14	**12a**	$TiCl_4$	1.1	−10	0.5	88	0	0	0	0	88	100/0
15		BF_3–OEt_2	1.1	−25	5.0	41	0	8	0	15	48	100/0

a) The following solvent were used: $TiCl_4$, BF_3–OEt_2, Me_3SiOTf, CF_3COOH in anhydrous CH_2Cl_2, Bu_4NF in anhydrous THF. *b*) The concentration of the substrate was 0.01 mol/l unless otherwise noted. *c*) The concentration of the substrate was 0.1 mol/l.

reaction (entries 6, 7, 9 and 15 in Table I). The structure of **15a** was determined from its mass spectrum (MS) (molecular ion peak at m/z 350), and its IR spectrum (no absorption band due to hydroxy group). The ^{1}H-NMR data of **15a** were almost identical with those of **13a** except for the signal due to the hydroxy group. Therefore, **15a** may have a symmetrical structure with *cis*-configuration. A benzene solution of the resulting hydroxy ester (**13a**) was heated with *p*-toluenesulfonic acid to give the *cis*-fused lactone (**16a**) in a good yield. Its IR and ^{1}H-NMR data, were identical with those of the *cis*-fused α-methylene-γ-lactone derivative (**16a**) reported by Murray *et al.*[21] and Yu and Helquist.[22]

Into Six-Membered Carbocycles When the allylsilanes (**11b** and **12b**) were cyclized to six-membered carbocyclic products, the stereochemical outcome was affected by both the geometry of the allylsilane, *E* or *Z*, and the nature of the Lewis acid employed. Treatment of the (*Z*)-allylsilane (**11b**) with titanium tetrachloride gave predominantly the *cis*-hydroxy ester (**13b**) and/or *cis*-lactone (**16b**), together with the *trans*-hydroxy ester (**14b**) as a minor product. When the Lewis acid was used in an amount of more than 2.0 eq, the *cis*/*trans* ratio was between 1.5 and 3.5, being independent of the reaction conditions, the amount of the acid, the concentration and the temperature (entries 4—11 in Table II). The ratio (*cis*/*trans*), however, was improved by the use of 1.1 eq of the acid (entries 2, 3). The cyclization reaction with boron trifluoride etherate or

TABLE II. Intramolecular Cyclization of the Allylsilanes (**11b** and **12b**)

Entry	Substrate	Reagent	eq	Reaction conditions[a,b]		Products yield (%)				Conv. to **13**, **14**, **16** (%)	Ratio *cis*/*trans*
				Temp. (°C)	Time (h)	**13b**	**16b**	**14b**	S.M.		
1	**11a**	$TiCl_4$	0.1	−10	1.0	No reaction					
2			1.1	−55	17.0	20	3	0	38	39	100/0
3			1.1	−10	4.0	72	10	6	5	93	93/7
4			2.0	−50	17.0	34	5	21	15	70	65/35
5			2.0	−30	20.0	55	0	27	9	90	67/33
6			2.0	−10	3.0	56	7	18	4	85	78/22
7			2.0	−10	3.0[c]	55	5	29	3	92	67/33
8			3.0[d]	−10	6.5[c]	52	2	28	0	82	66/34
9			3.0	−10	1.5	49	5	18	4	75	75/25
10			3.0	−20	0.8[c]	53	6	28	0	81	68/32
11			4.0	−5	4.0[c]	57	0	39	0	96	59/41
12		BF_3–OEt_2	1.1	−25	5.0	49	12	0	11	69	100/0
13			2.1	−25	5.0	48	0	0	0	48	100/0
14		$EtAlCl_2$	2.0	−30	5.0	Complex mixture			39	0	
15		Me_3SiOTf	0.1	−55	4.0	0	0	0	99	0	
16			0.1	r.t.	2.0	0	44	0	0	44	100/0
17			1.1	−55	1.0	32	0	0	0	32	100/0
18		CF_3CO_2H	2.1	40	4.0	No reaction					
19		Bu_4NF	0.1	<r.t.	3.0	No reaction					
20			0.1	70	10.0	Complex mixture					
21			1.1	−40	1.0	Complex mixture					
22	**12a**	$TiCl_4$	1.0	−10	1.0	44	37	0	0	81	100/0
23			2.0	−10	0.8	52	18	0	2	71	100/0
24		BF_3–OEt_2	1.1	−25	5.0	0	0	62	19	76	0/100
25			2.1	−25	5.0	0	0	66	0	66	0/100

a) The following solvent were used: $TiCl_4$, BF_3–OEt_2, Me_3SiOTf, CF_3COOH in anhydrous CH_2Cl_2, Bu_4NF in anhydrous THF, $EtAlCl_2$ in toluene. *b*) The concentration of the substrate was 0.01 mol/l unless otherwise noted. *c*) The concentration of the substrate was 0.1 mol/l. *d*) Reverse addition; the substrate was added to the solution of the Lewis acid.

TABLE III. Intramolecular Cyclization of the Allylsilanes (**11c, d** and **e**)

Entry	Substrate	Reagent	eq	Reaction conditions[a,b]		Yield (%)	
				Temp. (°C)	Time (h)	**18a**	S.M.
1	**11c**	$TiCl_4$	4.0	r.t.—40	24.0[c]	54	0
2		BF_3–OEt_2	5.0	r.t.	15.0[c]	57	0
3		Bu_4NF	5.0	0	0.5[c]	Complex mixture	
4	**11d**	$TiCl_4$	5.0	r.t.	24.0[c]	58	0
5	**11e**	$TiCl_4$	2.2	0	120.0	26	36
6			2.2	r.t.	20.0	83	—
7			2.2	r.t.	24.0[d]	71	2
8		$ZnCl_2$	2.2	r.t.	48.0	0	98

a) The following solvent were used: $TiCl_4$, BF_3–OEt_2, in anhydrous CH_2Cl_2, Bu_4NF in anhydrous THF, $ZnCl_2$ in anhydrous ether. *b*) The concentration of the substrate was 0.01 mol/l unless otherwise noted. *c*) The concentration of the substrate was 0.1 mol/l. *d*) The solution of the substrate was added dropwise over 7 h at the final concentration of 0.001 mol/l.

trimethylsilyl triflate exclusively afforded the *cis*-isomers (**13b** and/or **16b**) independently of the amount (1 or 2 eq) of the acid. On the other hand, treatment of the (*E*)-isomer (**12b**) with boron trifluoride etherate gave only the *trans*-hydroxy ester (**14b**) in good yield, though treatment with titanium tetrachloride gave the *cis*-hydroxy ester (**13b**) together with the *cis*-lactone (**16b**) in good yields. The configurations of the hydroxy esters (**13b** and **14b**) were deduced to be *cis* and *trans*, respectively, from their ^{1}H-NMR data; **13b** [δ 2.76 (br d, J=12 Hz, 2-H), 4.01 (br, $w_{h/2}$=5 Hz, 1-H)], **14b** [δ 2.50 (td, J=10, 3 Hz, 2-H), 3.57 (td, J=10, 4 Hz, 1-H)]. Lactonization reaction of the hydroxy esters (**13b** and **14b**) was performed by treatment with *p*-toluenesulfonic acid to afford the corresponding *cis*- and *trans*-lactones (**16b** and **17b**) in good yields. The structures of these lactones were determined by comparing their spectral data (IR and NMR) with those reported.[23] Thus, stereoselective syntheses of the *cis*- and *trans*-lactones (**16b** and **17b**) were achieved by suitable selection of the combination of the allylsilanes, *E* or *Z*, and the Lewis acids.

Mechanisms Though the reason for the stereoselectivity of this cyclization reaction is unclear, it should be related to the configuration of the Lewis acid–allylsilane complex at the transition state.[24] The stereochemical outcome of these cyclizations was anticipated to depend upon preferential transition states in the chair form which place the allylsilane moiety in a favored equatorial position.[18b] As depicted in Figs. 1, 2 and 3, the relative position of the formyl group and the allylic moiety of the transition structure determines the stereoselection. Boron trifluoride has only one acceptor site[25] and can coordinate the two carbonyl functions, aldehyde and ester. The electrophile, the aldehyde–boron trifluoride complex, attacks the surface of the olefin moiety *anti* to the trimethylsilyl group, as shown in Figs. 1 and 2.[26] Therefore, the ester group, with or without coordinating to boron trifluoride, would be bulkier than the (trimethylsilyl)methyl group. Consequently, among the two transition states (ZA and ZB) of (*Z*)-allylsilane (**11b**), conformation ZA, which leads to the *cis*-hydroxy ester, is sterically and electronically favored since it avoids the repulsion between the ester and the aldehyde group. The transition state EB of (*E*)-allylsilane (**12b**), which leads to the *trans*-isomer, is more favorable than the conformation EA for the same reason as above (Figs. 1 and 2). The secondary orbital effect,[27] focused on the HOMO of the allylmetal and LUMO of the

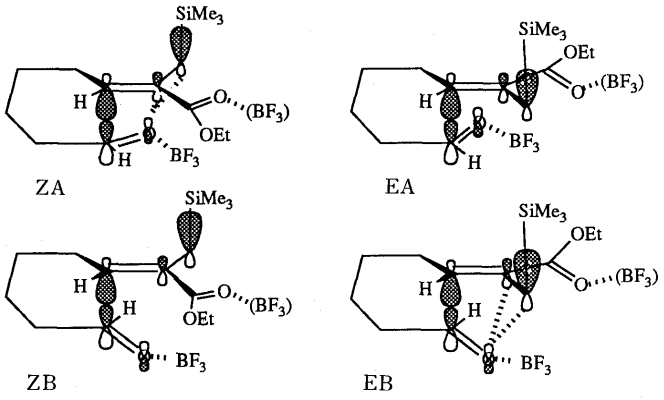


Fig. 1

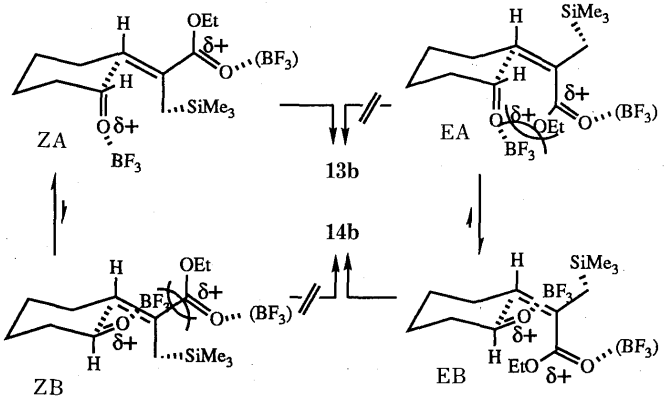


Fig. 2

Figs. 1 and 2. Transition State Conformations in the Cyclization of **11b** (ZA and ZB), and **12b** (EA and EB) in the Presence of BF_3

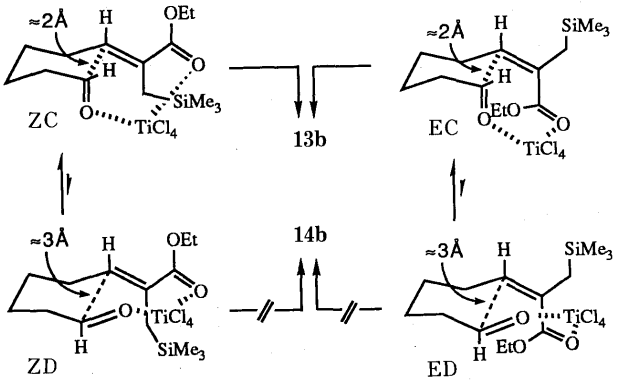


Fig. 3. Transition State Conformations in the Cyclization of **11b** (ZC and ZD), and **12b** (EC and ED) in the Presence of $TiCl_4$

complexed aldehyde, may partly influence the stability of the transition state. In the transition structures ZA and EB, there is an in-plane orbital overlap between the aldehyde oxygen and the silyl-bearing carbon which is absent in the structures ZB and EA (Fig. 1).

On the contrary, titanium tetrachloride has two acceptor sites,[25a-c,28] and can intramolecularly coordinate with both the formyl and the ester carbonyl groups of the allylsilanes by bridging at the transition states.[20] Poll *et al.*[28a] reported the crystal structure of acryloylmethyl lactate complex with titanium tetrachloride, which involves

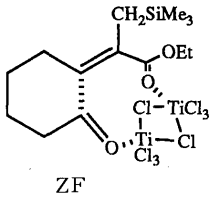


Fig. 4

a seven-membered chelating structure. On the basis of these crystallographic data [bond lengths (Å), O–Ti 2.1, Ti–Cl 2.2, C=O 1.25, angles (°), C–O–Ti ≈130, O–Ti–O≈80], the transition models (ZC, ZD, EC and ED) of **15b** and **16b** were proposed to be as shown in Fig. 3. The distances between the two reaction centers, aldehyde and olefin, were compared on Dreiding models of the transition structures, fixing the conformation of the six-membered ring moiety in the chair form. Among the transition models (ZC, ZD, EC and ED), ED and ZD, which lead to the *trans*-hydroxy ester (**14b**), would be disfavored since the formyl carbonyl group is situated rather far (≈3 Å) from the olefinic carbon.[27,29] Therefore, the (*E*)- and (*Z*)-allylsilanes (**11b** and **12b**) would be expected to afford the *cis*-products (**13b** and **16b**) exclusively, when 1 eq of titanium tetrachloride is used. Perhaps with more than 1 eq of titanium tetrachloride a bistitanium complex (ZF) could be partly formed,[29,30,31] which would react intramolecularly with a stereoselectivity different from that of ZC (Fig. 4). The *cis*-selectivity of the cyclization reaction into five-membered carbocycles may arise for different reasons, and is being investigated.

In summary, we have investigated the stereoselective intramolecular cyclization of ω-formylated β-(ethoxycarbonyl)allylsilanes into α-methylene-γ-lactones fused to carbocycles. The stereoselectivity of the cyclization reaction depends on both the geometry of the allylsilane and the nature of the Lewis acid. Further studies are in progress.

Experimental

All melting points were measured with a Yanaco hot-stage micro melting point apparatus and are uncorrected. ^{1}H-NMR and ^{13}C-NMR spectra were obtained on a JEOL FX-100 (100 MHz for ^{1}H) or in some cases on a Hitachi R-24B (60 MHz) spectrometer. All NMR spectra were recorded in $CDCl_3$ and are reported in parts per million (ppm) relative to tetramethylsilane (TMS) ($\delta=0.00$) or $CHCl_3$ ($\delta=7.25$) unless otherwise noted. The following abbreviations are used for the signal patterns: s=singlet, d=doublet, t=triplet, q=quartet, m=multiplet, and br=broad. IR spectra were run on a Hitachi 215 spectrophotometer. MS were recorded at 70 eV on a Hitachi M-80 spectrometer using a direct inlet system. Elemental analysis was carried out on a Heraeus CHN-Rapid elemental analyzer. MPLC was conducted on a LiChroprep Si 60 (Merck). Column chromatography was carried out on silica gel (BW-127 ZH, Fuji-Davison, 100—270 mesh) containing 2% fluorescence indicator F_{254} with a quartz column. Thin layer chromatography (TLC) was conducted on a Kieselgel 60 F_{254} (Art. 5715, Merck).

5-(Tetrahydropyranyloxy)pentanol (2a) A mixture of pentamethylene glycol (**1a**) (5.2 g, 50 mmol), 3,4-dihydro-2*H*-pyran (4.2 g, 50 mmol) and pyridinium *p*-toluenesulfonate (PPTS) (0.5 g, 2.0 mmol) in a mixture of CH_2Cl_2 (30 ml) and THF (10 ml) was stirred at room temperature for 6 h. The reaction mixture was diluted with CH_2Cl_2 (150 ml), washed with water and brine, and then dried over $MgSO_4$. The aqueous layer was concentrated *in vacuo* to give a residue. The starting glycol (1.15 g, 22.0%) was taken up from the residue with ethyl acetate. The CH_2Cl_2 extracts gave an oil, which was chromatographed on a silica gel column. Elution with 20% EtOAc–hexane gave 1,5-bis(tetrahydropyranyloxy)-pentane (**3a**) (1.467 g, 10.8%) as a colorless oil, and elution with 50%

EtOAc–hexane gave **2a** (4.375 g, 46.0%) as a colorless oil. Bulb to bulb distillation of the alcohol (**2a**) gave 3.89 g (41.3%) of a viscous oil (bp 135—145 °C (0.1—0.2 Torr)). **3a**: IR (neat) cm^{-1}: 2950, 1120, 1075, 1035. ^{1}H-NMR δ: 1.20—2.02 (18H, m, CH_2), 3.30—4.00 (8H, m, OCH_2), 4.60 (1H, br s, anomeric H). MS *m/z* (rel. intensity): 271 (M^+-1, <0.1), 187 (2), 157 (0.2), 101 (10), 85 (100). **2a**: IR (neat) cm^{-1}: 3400, 2950, 1030. ^{1}H-NMR δ: 1.20—2.10 (12H, m, CH_2), 1.88 (1H, s, OH), 3.40—3.90 (6H, m, OCH_2), 4.60 (1H, br s, anomeric H). MS *m/z* (rel. intensity): 187 (M^+-1, 0.2), 170 (M^+-H_2O, 0.1), 101 (19), 85 (100).

6-(Tetrahydropyranyloxy)hexanol (2b) Hexamethylene glycol (**1b**) (7.09 g, 60 mmol) was treated with 2*H*-dihydropyran (5.05 g, 60 mmol) and PPTS (0.7 g, 2.8 mmol) in a mixture of CH_2Cl_2 (20 ml) and THF (30 ml) for 3 h. Work-up as above gave a residual mixture, which was subjected to column chromatography with 20% EtOAc–hexane to give 1,6-bis(tetrahydropyranyloxy)hexane (**3b**) (0.94 g, 5.5%) as a colorless oil, the mono-alcohol (**2b**) (4.61 g, 38.0%) as a colorless oil (bp 130—140 °C (0.02 Torr)), and the starting glycol (2.58 g, 36.3%). **3b**: IR (neat) cm^{-1}: 2940, 1035. ^{1}H-NMR δ: 1.20—1.90 (20H, m, CH_2), 3.25—4.00 (8H, m, OCH_2), 4.54 (1H, br s, anomeric H). MS *m/z* (rel. intensity): 286 (M^+, <0.1), 285 (0.1), 201 (7), 101 (16), 85 (100). **2b**: IR (neat) cm^{-1}: 3400, 1035, 1030. ^{1}H-NMR δ: 1.20—1.90 (14H, m, CH_2), 1.80 (1H, s, OH), 3.20—4.00 (6H, m, OCH_2), 4.55 (1H, br s, anomeric H). MS *m/z* (rel. intensity): 201 (M^+-1, 0.6), 117 (3), 101 (30), 85 (100).

7-(Tetrahydropyranyloxy)heptanol (2c) In a similar manner, **2c** was synthesized from 1,7-heptanediol in 40.3% (conversion 81.8%) yield. IR (neat) cm^{-1}: 3400, 1035, 1030. ^{1}H-NMR δ: 1.20—1.90 (16H, m, CH_2), 1.80 (1H, s, OH), 3.20—4.00 (6H, m, OCH_2), 4.55 (1H, br s, anomeric H). MS *m/z* (rel. intensity): 215 (M^+-1, 0.1), 115 (5), 101 (20), 97 (25), 85 (100), 55 (50).

10-(Tetrahydropyranyloxy)decanol (**2d**) and 14-(tetrahydropyranyloxy)-tetradecanol (**2e**) were synthesized from the corresponding diols.[7]

5-(Tetrahydropyranyloxy)pentanal (4a) Dimethyl sulfoxide (3.98 ml, 56 mmol) was added to a stirred solution of oxalyl chloride (2.27 ml, 26 mmol) in CH_2Cl_2 (40 ml) at −50—−60 °C under argon. The reaction mixture was stirred at the same temperature for 10 min and then a CH_2Cl_2 solution of the alcohol (**2a**) (3.83 g, 20.3 mmol in 20 ml) was added within 10 min, and stirring was continued for an additional 30 min. Triethylamine (18.2 ml, 130 mmol) was added, and the mixture was stirred for 20 min and then allowed to warm to room temperature. Water (60 ml) was added and the aqueous layer was extracted with CH_2Cl_2 (200 ml). The combined organic layer was washed with cold 5% HCl, 10% $NaHCO_3$ and brine, and then dried over $MgSO_4$. The solvent was evaporated, and the residue was purified by column chromatography with 20% EtOAc–hexane followed by bulb-to-bulb distillation to give the aldehyde (**4a**) (3.24 g, 85.6%, bp 115—120 °C (0.2 Torr)). IR (neat) cm^{-1}: 1725, 1035. ^{1}H-NMR δ: 1.40—2.00 (10H, m, CH_2), 2.50 (2H, td, J=7, 2 Hz, $C\underline{H}_2CHO$), 3.30—4.00 (4H, m, OCH_2), 4.59 (1H, br s, anomeric H), 9.83 (1H, t, J=2 Hz, CHO). MS *m/z* (rel. intensity): 186 (M^+, 0.1), 156 (M^+-HCHO, 1.5), 128 (1.5), 101 (11), 85 (100). High-resolution MS Calcd for $C_{10}H_{18}O_3$ (M^+): 186.1254. Found: 186.1255. Other aldehydes (**4b**, **c**, **d** and **e**) were also obtained from the corresponding alcohols (**2b**—**e**) by this method.

6-(Tetrahydropyranyloxy)hexanal (**4b**): Yield 88.5%, bp 130 °C (0.7 Torr). IR (neat) cm^{-1}: 1725, 1035. ^{1}H-NMR δ: 1.30—1.90 (12H, m, CH_2), 2.42 (2H, td, J=7, 2 Hz, $C\underline{H}_2CHO$), 3.20—4.00 (4H, m, OCH_2), 4.54 (1H, br s, anomeric H), 9.72 (1H, t, J=2 Hz, CHO). MS *m/z* (rel. intensity): 200 (M^+, 0.1), 199 (1.5), 170 (0.5), 156 (0.5), 101 (25), 99 (20), 85 (100). High-resolution MS Calcd for $C_{11}H_{20}O_3$ (M^+): 200.1411. Found: 200.1384.

7-(Tetrahydropyranyloxy)heptanal (**4c**): Yield 93.9%, bp 130—135 °C (0.2 Torr). IR (neat) cm^{-1}: 1725, 1035. ^{1}H-NMR δ: 1.30—1.90 (14H, m, CH_2), 2.42 (2H, td, J=7, 2 Hz, $C\underline{H}_2CHO$), 3.20—4.00 (4H, m, OCH_2), 4.56 (1H, br s, anomeric H), 9.72 (1H, t, J=2 Hz, CHO). MS *m/z* (rel. intensity): 214 (M^+, 0.4), 213 (1), 184 (0.2), 159 (0.4), 141 (0.7), 95 (27), 85 (100). High-resolution MS Calcd for $C_{12}H_{22}O_3$ (M^+): 214.1566. Found: 214.1562. The data for **4d** and **4e** were cited in reference 7.

Ethyl 3-Hydroxy-7-(tetrahydropyranyloxy)-2-(trimethylsilylmethyl)-heptanoate (5a) A THF solution of ethyl β-trimethylsilylpropionate (2.77 ml, 13.9 mmol in 5 ml) was added to a THF solution of LDA (13.9 mmol in 50 ml), prepared from diisopropylamine (1.95 ml, 13.9 mmol) and butyllithium (1.5 M solution in hexane, 9.25 ml, 13.9 mmol), at −78 °C under argon. The mixture was stirred at the same temperature for 20 min, and then a THF solution of the aldehyde (**4a**) (2.0 g, 10.75 mmol in 11 ml) was added to the enolate over 30 min. The mixture was stirred at −78 °C for 1 h, and then the reaction was quenched by addition of saturated NH_4Cl solution. The whole was extracted with ether, and the extracts were washed with cold 5% HCl, 10% $NaHCO_3$ and brine, and then dried over $MgSO_4$. Removal of the solvent gave a crude oil (4.3 g), which was purified by column chromatography with 25% EtOAc–hexane to give a diastereomeric mixture of the hydroxy esters (**5a**) as a colorless oil (3.26 g, 84.3%). IR (neat) cm^{-1}: 3470, 1735, 860, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 0.76—0.96 (2H, m, CH_2TMS), 1.30 (3H, t, J=7 Hz, $COOCH_2C\underline{H}_3$), 1.33—1.73 (12H, m, CH_2), 2.28 (1H, s, OH), 2.48 (1H, dt, J=11, 5 Hz, CHCOOEt), 3.38—3.98 (5H, m, 3,7-H, $-OCH_2$ of 2-tetrahydropyranyl (THP)), 4.16 (2H, q, J=7 Hz, $COOCH_2$), 4.58 (1H, br s, anomeric H). MS *m/z* (rel. intensity): 315 (<0.1), 257 (2), 243 (3), 174 (25), 173 (6), 129 (5), 95 (12), 85 (100).

Ethyl 3-Hydroxy-8-(tetrahydropyranyloxy)-2-(trimethylsilylmethyl)-octanoate (5b) By a procedure similar to that described for **5a**, the aldehyde (**4b**) (4.72 g, 23.5 mmol) gave a diastereomeric mixture of the hydroxy esters (**5b**) (7.66 g, 86.8%). A sample of the less polar component: an oil. IR (neat) cm^{-1}: 3450, 1735, 860, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 0.76—0.96 (2H, m, CH_2TMS), 1.29 (3H, t, J=7 Hz, $COOCH_2C\underline{H}_3$), 1.33—1.73 (14H, m, CH_2), 2.22 (1H, s, OH), 2.50 (1H, dt, J=11, 5 Hz, CHCOOEt), 3.38—3.90 (5H, m, 3,8-H, $-OCH_2$ of THP), 4.17 (2H, q, J=7 Hz, $COOCH_2$), 4.58 (1H, br s, anomeric H). MS *m/z* (rel. intensity): 340 (M^+-34, 0.2), 301 (0.2), 257 (4), 241 (3), 174 (40), 85 (100). A sample of the polar component: an oil, IR (neat) cm^{-1}: 3450, 1735, 860, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 0.83—1.01 (2H, m, CH_2TMS), 1.29 (3H, t, J=7 Hz, $COOCH_2C\underline{H}_3$), 1.33—1.73 (14H, m, CH_2), 2.50 (1H, s, OH), 2.50 (1H, dt, J=10, 5 Hz, CHCOOEt), 3.30—3.90 (5H, m, 3,8-H, $-OCH_2$ of THP), 4.18 (2H, q, J=7 Hz, $COOCH_2$), 4.58 (1H, br s, anomeric H). MS *m/z* (rel. intensity): 359 (M^+-15, <0.1), 301 (0.4), 257 (4), 241 (4), 174 (40), 85 (100).

Ethyl 3-Hydroxy-9-(tetrahydropyranyloxy)-2-(trimethylsilylmethyl)-nonanoate (5c) By a procedure similar to that described for **5a**, the aldehyde (**4c**) (2.15 g, 10.0 mmol) gave a diastereomeric mixture of the hydroxy esters (**5c**) as a colorless oil (2.45 g, 63.8%). IR (neat) cm^{-1}: 3470, 1730, 1250, 1035, 860, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 0.76—0.96 (2H, m, CH_2TMS), 1.26 (3H, t, J=7 Hz, $COOCH_2C\underline{H}_3$), 1.33—1.73 (16H, m, CH_2), 2.13 (1H, s, OH), 2.44 (1H, dt, J=11, 5 Hz, CHCOOEt), 3.20—3.98 (5H, m, 3,9-H, $-OCH_2$ of THP), 4.10 (2H, q, J=7 Hz, $COOCH_2$), 4.52 (1H, br s, anomeric H). MS *m/z* (rel. intensity): 388 (M^+, <0.1), 373 (0.2), 370 (0.2), 341 (0.2), 289 (3), 216 (3), 174 (43), 85 (100). High-resolution MS Calcd for $C_{20}H_{40}O_5Si$ (M^+): 388.2643. Found: 388.2673.

Ethyl 3-Hydroxy-12-(tetrahydropyranyloxy)-2-(trimethylsilylmethyl)-dodecanoate (5d) By a procedure similar to that described for **5a**, the aldehyde (**4d**) (2.05 g, 8.0 mmol) gave a diastereomeric mixture of the hydroxy esters (**5d**) as a colorless oil (2.47 g, 71.7%) together with **4d**, in 18.7% yield. IR (neat) cm^{-1}: 3470, 1730, 1250, 1035, 860, 845. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 0.70—1.00 (2H, m, CH_2TMS), 1.26 (3H, t, J=7 Hz, $COOCH_2C\underline{H}_3$), 1.20—1.90 (22H, m, CH_2), 2.00 (1H, s, OH), 2.46 (1H, dt, J=11, 5 Hz, CHCOOEt), 3.20—3.98 (5H, m, 3,12-H, $-OCH_2$ of THP), 4.10 (2H, q, J=7 Hz, $COOCH_2$), 4.52 (1H, br s, anomeric H). MS *m/z* (rel. intensity): 430 (M^+, <0.1), 429 (0.1), 412 (0.1), 383 (0.2), 357 (0.3), 174 (37), 85 (100). High-resolution MS Calcd for $C_{23}H_{46}O_5Si$ (M^+): 430.3111. Found: 430.3110.

Ethyl 3-Hydroxy-16-(tetrahydropyranyloxy)-2-(trimethylsilylmethyl)-hexadecanoate (5e) By a procedure similar to that described for **5a**, the aldehyde (**4e**) (300 mg, 0.96 mmol) gave a diastereomeric mixture of the hydroxy esters (**5e**) as a colorless oil (395 mg, 84.4%). IR (neat) cm^{-1}: 3470, 1730, 1250, 1030, 855, 840. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 0.76—1.00 (2H, m, CH_2TMS), 1.24 (3H, t, J=7 Hz, $COOCH_2C\underline{H}_3$), 1.1—1.8 (24H, m, CH_2), 2.02 (1H, s, OH), 2.46 (1H, dt, J=11, 5 Hz, CHCOOEt), 3.20—3.98 (5H, m, 3,16-H, $-OCH_2$ of THP), 4.10 (2H, q, J=7 Hz, $COOCH_2$), 4.53 (1H, br s, anomeric H). MS *m/z* (rel. intensity): 486 (M^+, <0.1), 485 (<0.1), 468 (M^+-H_2O, 0.1), 413 (4), 229 (5), 174 (47), 85 (100).

Ethyl (2*Z*)-7-(Tetrahydropyranyloxy)-2-(trimethylsilylmethyl)-2-heptenoate (7a) Methanesulfonyl chloride (0.263 ml, 3.4 mmol) was added to the diastereomeric mixture of the hydroxy esters (**5a**) (940 mg, 2.61 mmol) and triethylamine (0.98 ml, 7.0 mmol) in CH_2Cl_2 (20 ml) at −8 °C. The mixture was stirred at −5 °C for 30 min, and poured into ice-water. The whole was extracted with CH_2Cl_2, and the extracts were washed with cold 5% HCl, 10% $NaHCO_3$ and brine, and then dried. Removal of the solvent followed by column chromatography with CH_2Cl_2 gave a diastereomeric mixture of the mesylates (**6a**) (1.10 g, 96.8%) as an oil. Data of the mixture: IR (neat) cm^{-1}: 1735, 1350, 845. ^{1}H-NMR δ: 0.00

(9H, s, $SiMe_3$), 0.58—1.06 (2H, m, CH_2TMS), 1.30 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 2.70—2.96 (1H, m, CHCOOEt), 3.00, 3.05 (3H, s, mesyl), 3.25—3.95 (4H, m, $OC\underline{H}_2$), 4.16, 4.17 (2H, q, $J=7$ Hz, $COOCH_2$), 4.57 (1H, br s, anomeric H), 4.82, 4.89 (1H, q, $J=6$ Hz, C<u>H</u>OMs). MS *m/z* (rel. intensity): 438 (M^+, <0.1), 437 (0.3), 423 (1.1), 327 (5), 259 (5), 243 (28), 173 (31), 153 (15), 95 (23), 85 (100).

The mixture of the above mesylates (1.04 g, 2.37 mmol) and DBU (434 mg, 2.85 mmol) in dry benzene (40 ml) was heated at reflux temperature for 10 h. The reaction mixture was diluted with benzene, and washed with 5% HCl, 10% $NaHCO_3$ and brine, and then dried. Removal of the solvent afforded an α,β-unsaturated ester (**7a**) (805 mg, 99.2%), which was purified by column chromatography with 10% EtOAc–hexane to give the pure ester (**7a**) (717 mg, 88.5%) as a colorless oil. IR (neat) cm^{-1}: 1710, 1635, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 1.30 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 1.82 (2H, s, CH_2TMS), 2.15 (2H, q, 4-H), 3.00—3.90 (4H, m, OCH_2), 4.19 (2H, q, $J=7$ Hz, $COOCH_2$), 4.58 (1H, br s, anomeric H), 6.64 (1H, t, $J=7$ Hz, =CH). MS *m/z* (rel. intensity): 342 (M^+, 0.5), 327 (5), 258 (17), 243 (6), 185 (35), 95 (17), 85 (100). High-resolution MS Calcd for $C_{18}H_{34}O_4Si$ (M^+): 342.2223. Found: 342.2206.

Ethyl (2*Z*)-8-(Tetrahydropyranyloxy)-2-(trimethylsilylmethyl)-2-octenoate (7b) By a procedure similar to that described for **7a**, methanesulfonylation of the alcohols (**5b**) (1.56 g, 4.16 mmol) was effected with methanesulfonyl chloride (0.42 ml, 5.42 mmol) and triethylamine (1.55 ml, 11.2 mmol) in CH_2Cl_2 (30 ml). The crude product was purified to give a diastereomeric mixture of the mesylates (**6b**) (1.62 g, 85.8%) as a colorless oil. Data of the mixture: IR (neat) cm^{-1}: 1730, 1350, 1175, 840. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 0.60—1.00 (2H, m, CH_2TMS), 1.28 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 2.80 (1H, ddd, $J=12$, 6, 3 Hz, CHCOOEt), 3.02, 3.06 (3H, s, mesyl), 3.30—3.90 (4H, m, OCH_2), 4.14 (2H, q, $J=7$ Hz, $COOCH_2$), 4.56 (1H, br s, anomeric H), 4.80 (1H, q, $J=6$ Hz, CHOMs). MS *m/z* (rel. intensity): 452 (M^+, <0.1), 451 (0.4), 437 (0.3), 423 (2), 327 (5), 257 (46), 173 (66), 153 (38), 95 (23), 85 (100).

The mixture of the mesylates (1.62 g) was treated with DBU (0.64 ml, 4.3 mmol) in dry benzene (60 ml) at reflux temperature for 10 h. The chromatographic purification of the crude material gave an α,β-unsaturated ester (**7b**) (0.95 g, 74.3%) as a colorless oil. IR (neat) cm^{-1}: 1710, 1635, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 1.31 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 1.82 (2H, s, CH_2TMS), 2.14 (2H, br q, $J=7$ Hz, 4-H), 3.20—3.90 (4H, m, OCH_2), 4.20 (2H, q, $J=7$ Hz, $COOCH_2$), 4.58 (1H, br s, anomeric H), 6.64 (1H, t, $J=7$ Hz, =CH). MS *m/z* (rel. intensity): 356 (M^+, 0.6), 341 (M^+-Me, 5), 272 (19), 185 (48), 85 (100). High-resolution MS Calcd for $C_{19}H_{36}O_4Si$ (M^+): 356.2381. Found: 356.2376.

Ethyl (2*Z*)-9-(Tetrahydropyranyloxy)-2-(trimethylsilylmethyl)-2-nonenoate (7c) By a procedure similar to that described for **7a**, methanesulfonylation of the alcohols (**5c**) (2.41 g, 6.22 mmol) gave a diastereomeric mixture of the mesylates (**6c**) (2.62 g, 90.3%) as a colorless oil. IR (neat) cm^{-1}: 1735, 1350, 1175, 910, 845. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 0.50—1.10 (2H, m, CH_2TMS), 1.26 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 2.76 (1H, m, C<u>H</u>COOEt), 2.94, 3.00 (3H, s, mesyl), 3.30—3.90 (4H, m, OCH_2), 4.12 (2H, q, $J=7$ Hz, $COOCH_2$), 4.51 (1H, br s, anomeric H), 4.75 (1H, q, $J=6$ Hz, CHOMs). MS *m/z* (rel. intensity): 466 (M^+, <0.1), 465 (0.4), 371 (2), 355 (2), 271 (8), 173 (22), 153 (11), 85 (100).

The mesylates (2.34 g) were treated with DBU to give an α,β-unsaturated ester (**7c**) (1.36 g, 73.1%) as a colorless oil. IR (neat) cm^{-1}: 1710, 1635, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 1.28 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 1.78 (2H, s, CH_2TMS), 2.06 (2H, br q, $J=7$ Hz, 4-H), 3.20—3.90 (4H, m, OCH_2), 4.14 (2H, q, $J=7$ Hz, $COOCH_2$), 4.52 (1H, br s, anomeric H), 6.58 (1H, t, $J=7$ Hz, =CH). MS *m/z* (rel. intensity): 370 (M^+, 1), 355 (M^+-Me, 5), 286 (5), 282 (5), 200 (9), 185 (48), 156 (33), 85 (100). High-resolution MS Calcd for $C_{20}H_{38}O_4Si(M^+)$: 370.2537. Found: 370.2541.

Ethyl (2*Z*)-12-(Tetrahydropyranyloxy)-2-(trimethylsilylmethyl)-2-dodecenoate (7d) By a procedure similar to that described for **7a**, methanesulfonylation of the alcohols (**5d**) (1.94 g, 4.50 mmol) gave a diastereomeric mixture of the mesylates (**6d**) (2.3 g, quant.) as a colorless oil. IR (neat) cm^{-1}: 1735, 1350, 1175, 910, 845. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 0.50—1.10 (2H, m, CH_2TMS), 1.26 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 2.76 (1H, m, CHCOOEt), 2.94, 3.00 (3H, s, mesyl), 3.20—3.90 (4H, m, OCH_2), 4.12 (2H, q, $J=7$ Hz, $COOCH_2$), 4.51 (1H, br s, anomeric H), 4.75 (1H, q, $J=6$ Hz, CHOMs). MS *m/z* (rel. intensity): 508 (M^+, <0.1), 507 (0.1), 397 (0.15), 313 (15), 283 (4), 173 (28), 153 (15), 85 (100).

The mesylates (2.19 g) were treated with DBU to give an α,β-unsaturated ester (**7d**) (1.64 g, 92.2%) as a colorless oil. IR (neat) cm^{-1}: 1710, 1635, 1250, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 1.28 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 1.78 (2H, s, CH_2TMS), 2.06 (2H, br q, $J=7$ Hz, 4-H), 3.20—3.90 (4H, m, OCH_2), 4.14 (2H, q, $J=7$ Hz, $COOCH_2$), 4.52 (1H, br s, anomeric H), 6.58 (1H, t, $J=7$ Hz, =CH). MS *m/z* (rel. intensity): 412 (M^+, 0.5), 397 (M^+-Me, 1.5), 383 (0.1), 313 (4), 267 (3), 185 (25), 156 (30), 85 (100). High-resolution MS Calcd for $C_{23}H_{44}O_4Si$ (M^+): 412.3006. Found: 412.3000.

Ethyl (2*Z*)-16-(Tetrahydropyranyloxy)-2-(trimethylsilylmethyl)-2-hexadecenoate (7e) The mixture of the alcohols (**5e**) (350 mg, 0.72 mmol) was acylated with methanesulfonyl chloride to give a diastereomeric mixture of the mesylates (**6e**) (400 mg, quant.) as a colorless oil. IR (neat) cm^{-1}: 1735, 1350, 1175, 900, 840. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 0.50—1.10 (2H, m, CH_2TMS), 1.26 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 2.78 (1H, m, CHCOOEt), 2.94, 3.00 (3H, s, mesyl), 3.20—3.90 (4H, m, OCH_2), 4.12 (2H, q, $J=7$ Hz, $COOCH_2$), 4.51 (1H, br s, anomeric H), 4.76 (1H, q, $J=6$ Hz, CHOMs). MS *m/z* (rel. intensity): 564 (M^+, <0.1), 563 (0.1), 549 (0.1), 465 (1.2), 369 (22), 323 (5), 283 (4), 173 (38), 153 (23), 84 (96), 55 (100).

The mesylates (394 mg) were treated with DBU to give an α,β-unsaturated ester (**7e**) (308 mg, 94.2%) as a colorless oil. IR (neat) cm^{-1}: 1710, 1635, 1250, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 1.30 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 1.80 (2H, s, CH_2TMS), 2.06 (2H, br q, $J=7$ Hz, 4-H), 3.20—3.90 (4H, m, OCH_2), 4.14 (2H, q, $J=7$ Hz, $COOCH_2$), 4.54 (1H, br s, anomeric H), 6.58 (1H, t, $J=7$ Hz, =CH). MS *m/z* (rel. intensity): 468 (M^+, 0.6), 453 (M^+-Me, 0.8), 439 (0.4), 369 (4), 323 (3), 185 (20), 156 (25), 85 (100). High-resolution MS Calcd for $C_{27}H_{52}O_4Si$ (M^+): 468.3632. Found: 468.3629.

Synthesis of 7b from 4b without Purification of the Intermediates The hexanal (**4b**) (4.0 g, 20 mmol) was allowed to react with the enolate of ethyl β-trimethylsilylpropionate (26 mmol) to give the adduct (**5b**), which was treated with methanesulfonyl chloride and triethylamine followed by DBU to afford **7b** (5.37 g, 75.4% yield from **4b**).

Ethyl (2*Z*)-7-Hydroxy-2-(trimethylsilylmethyl)-2-heptenoate (9a) A solution of the THP-ether (**7a**) (1.90 g, 5.55 mmol) and PPTS (160 mg, 0.6 mmol) in ethanol (40 ml) was stirred at 50 °C for 5 h. The ethanol was evaporated, and the residue was extracted with EtOAc. The extract was washed with water and brine, and dried over $MgSO_4$. Removal of the solvent gave 1.47 g of a residue, which was chromatographed on a silica gel column. Elution with 20% EtOAc–hexane and then with 30% EtOAc–hexane gave **7a** (79 mg, 4.2%) and the alcohol (**9a**) (1.04 g, 72.5%), respectively. IR (neat) cm^{-1}: 3400, 1710, 1635, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 1.31 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 1.82 (2H, s, CH_2TMS), 1.82 (1H, s, OH), 2.15 (2H, q, $J=7$ Hz, 4-H), 3.68 (2H, t, $J=6$ Hz, 7-H), 4.20 (2H, q, $J=7$ Hz, $COOCH_2$), 6.63 (1H, t, $J=7$ Hz, =CH). MS *m/z* (rel. intensity): 258 (M^+, 10), 243 (17), 213 (17), 185 (72), 95 (25), 73 (100). High-resolution MS Calcd for $C_{13}H_{26}O_3Si$ (M^+): 258.1649. Found: 258.1640.

Ethyl (2*Z*)-8-Hydroxy-2-(trimethylsilylmethyl)-2-octenoate (9b) By a procedure similar to that for **9a**, the THP-ether (**7b**) (2.95 g, 8.27 mmol) afforded the alcohol (**9b**) (2.18 g, 96.7%) as a colorless oil together with the starting material (0.11 g, 3.7%). IR (neat) cm^{-1}: 3350, 1710, 1635, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 1.32 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 1.50 (1H, s, OH), 1.83 (2H, s, CH_2TMS), 2.14 (2H, q, $J=7$ Hz, 4-H), 3.67 (2H, t, $J=7$ Hz, 8-H), 4.20 (2H, q, $J=7$ Hz, $COOCH_2$), 6.64 (1H, t, $J=7$ Hz, =CH). MS *m/z* (rel. intensity): 272 (M^+, 10), 257 (19), 227 (14), 185 (84), 73 (100). High-resolution MS Calcd for $C_{14}H_{28}O_3Si$ (M^+): 272.1806. Found: 272.1820.

Ethyl (2*Z*)-9-Hydroxy-2-(trimethylsilylmethyl)-2-nonenoate (9c) By a procedure similar to that for **9a**, the THP-ether (**7c**) (1.31 g, 3.53 mmol) gave the alcohol (**9c**) (873 mg, 86.3%) as a colorless oil together with the starting material (67 mg, 5.1%). IR (neat): cm^{-1}: 3350, 1710, 1635, 1250, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 1.30 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 1.60 (1H, s, OH), 1.80 (2H, s, CH_2TMS), 2.08 (2H, q, $J=7$ Hz, 4-H), 3.64 (2H, t, $J=7$ Hz, 9-H), 4.16 (2H, q, $J=7$ Hz, $COOCH_2$), 6.58 (1H, t, $J=7$ Hz, =CH). MS *m/z* (rel. intensity): 286 (M^+, 10), 271 (26), 241 (17), 213 (8), 200 (17), 185 (100), 157 (14), 95 (25), 73 (99). High-resolution MS Calcd for $C_{15}H_{30}O_3Si$ (M^+): 286.1961. Found: 286.1945.

Ethyl (2*Z*)-12-Hydroxy-2-(trimethylsilylmethyl)-2-dodecenoate (9d) By a procedure similar to that for **9a**, the THP-ether (**7d**) (1.50 g, 3.63 mmol) gave the alcohol (**9d**) (1.03 g, 86.6%) as a colorless oil together with the starting material (133 mg, 8.9%). IR (neat) cm^{-1}: 3350, 1710, 1635, 1250, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 1.30 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 1.60 (1H, s, OH), 1.80 (2H, s, CH_2TMS), 2.08 (2H, q, $J=7$ Hz, 4-H), 3.64 (2H, t, $J=7$ Hz, 12-H), 4.16 (2H, q, $J=7$ Hz,

$COOCH_2$), 6.58 (1H, t, $J=7$ Hz, =CH). MS *m/z* (rel. intensity): 328 (M^+, 4), 313 (20), 283 (9), 213 (4), 200 (11), 185 (70), 169 (10), 157 (10), 95 (30), 73 (100). High-resolution MS Calcd for $C_{18}H_{36}O_3Si$ (M^+): 328.2431. Found: 328.2423.

Ethyl (2*Z*)-16-Hydroxy-2-(trimethylsilylmethyl)-2-hexadecenoate (9e) By a procedure similar to that for **9a**, the THP-ether (**7e**) (280 mg, 0.60 mmol) gave the alcohol (**9e**) (209 mg, 91.0%) as a colorless oil. IR (neat) cm^{-1}: 3350, 1710, 1635, 1250, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 1.30 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 1.48 (1H, s, OH), 1.80 (2H, s, CH_2TMS), 2.08 (2H, q, $J=7$ Hz, 4-H), 3.64 (2H, t, $J=7$ Hz, 16-H), 4.16 (2H, q, $J=7$ Hz, $COOCH_2$), 6.58 (1H, t, $J=7$ Hz, =CH). MS *m/z* (rel. intensity): 384 (M^+, 4), 369 (14), 339 (6), 200 (11), 185 (64), 169 (8), 95 (26), 73 (100). High-resolution MS Calcd for $C_{22}H_{44}O_3Si$ (M^+): 384.3057. Found: 384.3063.

Ethyl (2*Z*)-6-Formyl-2-(trimethylsilylmethyl)-2-hexenoate (11a) Swern oxidation[13] of the alcohol (**9a**) (886 mg, 3.43 mmol) was performed by a method similar to that described for the synthesis of **8a**, using oxalyl chloride (0.42 ml, 4.8 mmol), dimethyl sulfoxide (0.71 ml, 10 mmol) and triethylamine (2.36 ml, 17 mmol). The crude material was purified by column chromatography with 20% EtOAc–hexane to give the aldehyde (**11a**) (800 mg, 91.0%) as a colorless oil. IR (neat) cm^{-1}: 1730, 1710, 1635, 1250, 1175, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 1.30 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 1.82 (2H, s, CH_2TMS), 1.82 (2H, quintet, $J=7$ Hz, 5-H), 2.12 (2H, q, $J=7$ Hz, 4-H), 2.51 (2H, td, $J=7$, 1.5 Hz, 6-H), 4.20 (2H, q, $J=7$ Hz, $COOCH_2$), 6.58 (1H, t, $J=7$ Hz, =CH), 9.69 (1H, t, $J=1.5$ Hz, CHO). MS *m/z* (rel. intensity): 256 (M^+, 3), 241 (6), 211 (7), 200 (22), 195 (15), 185 (34), 93 (16), 73 (100). High-resolution MS Calcd for $C_{13}H_{24}O_3Si$ (M^+): 256.1493. Found: 256.1489.

Ethyl (2*Z*)-7-Formyl-2-(trimethylsilylmethyl)-2-heptenoate (11b) Swern oxidation of the alcohol (**9b**) (1.166 g, 4.28 mmol) was performed by a method similar to that described for **11a**. The crude material was purified by column chromatography with 20% EtOAc–hexane to give the aldehyde (**11b**) (1.046 g, 90.4%) as a colorless oil. IR (neat) cm^{-1}: 1730, 1710, 1640, 1250, 1175, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 1.32 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 1.83 (2H, s, CH_2TMS), 2.16 (2H, q, $J=7$ Hz, 4-H), 2.50 (2H, td, $J=7$, 2 Hz, 7-H), 4.20 (2H, q, $J=7$ Hz, $COOCH_2$), 6.61 (1H, t, $J=7$ Hz, =CH), 9.70 (1H, t, $J=2$ Hz, CHO). MS *m/z* (rel. intensity): 270 (M^+, 5), 255 (M^+-Me, 7), 209 (13), 185 (48), 73 (100). High-resolution MS Calcd for $C_{14}H_{26}O_3Si$ (M^+): 270.1649. Found: 270.1643.

Ethyl (2*Z*)-8-Formyl-2-(trimethylsilylmethyl)-2-octenoate (11c) By a procedure similar to that for **11a**, the alcohol (**9c**) (793 mg, 2.77 mmol) gave the aldehyde (**11c**) (667 mg, 84.7%) as a colorless oil. IR (neat) cm^{-1}: 1730, 1710, 1635, 1250, 1175, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 1.30 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 1.80 (2H, s, CH_2TMS), 2.08 (2H, q, $J=7$ Hz, 4-H), 2.44 (2H, td, $J=7$, 2 Hz, 8-H), 4.17 (2H, q, $J=7$ Hz, $COOCH_2$), 6.56 (1H, t, $J=7$ Hz, =CH), 9.75 (1H, t, $J=2$ Hz, CHO). MS *m/z* (rel. intensity): 284 (M^+, 2), 269 (M^+-Me, 8), 239 (5), 185 (40), 73 (100). High-resolution MS Calcd for $C_{15}H_{28}O_3Si$ (M^+): 284.1805. Found: 284.1798.

Ethyl (2*Z*)-11-Formyl-2-(trimethylsilylmethyl)-2-dodecenoate (11d) By a procedure similar to that for **11a**, the alcohol (**9d**) (922 mg, 2.81 mmol) gave the aldehyde (**11d**) (856 mg, 93.5%) as a colorless oil. IR (neat) cm^{-1}: 1730, 1710, 1635, 1250, 1175, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 1.30 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 1.80 (2H, s, CH_2TMS), 2.08 (2H, q, $J=7$ Hz, 4-H), 2.40 (2H, td, $J=7$, 2 Hz, 11-H), 4.17 (2H, q, $J=7$ Hz, $COOCH_2$), 6.58 (1H, t, $J=7$ Hz, =CH), 9.74 (1H, t, $J=2$ Hz, CHO). MS *m/z* (rel. intensity): 326 (M^+, 10), 311 (M^+-Me, 37), 281 (13), 200 (20), 185 (100), 73 (92). High-resolution MS Calcd for $C_{18}H_{34}O_3Si$ (M^+): 326.2275. Found: 326.2261.

Ethyl (2*Z*)-15-Formyl-2-(trimethylsilylmethyl)-2-pentadecenoate (11e) By a procedure similar to that for **11a**, the alcohol (**9e**) (185 mg, 0.48 mmol) gave the aldehyde (**11e**) (170 mg, 92.6%) as a colorless oil. IR (neat) cm^{-1}: 1730, 1710, 1635, 1250, 1175, 850. ^{1}H-NMR δ: 0.00 (9H, s, $SiMe_3$), 1.30 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 1.81 (2H, s, CH_2TMS), 2.08 (2H, q, $J=7$ Hz, 4-H), 2.40 (2H, td, $J=7$, 2 Hz, 15-H), 4.17 (2H, q, $J=7$ Hz, $COOCH_2$), 6.58 (1H, t, $J=7$ Hz, =CH), 9.75 (1H, t, $J=2$ Hz, CHO). MS *m/z* (rel. intensity): 382 (M^+, 10), 367 (M^+-Me, 25), 337 (9), 323 (6), 213 (8), 200 (18), 185 (96), 73 (100). High-resolution MS Calcd for $C_{22}H_{42}O_3Si$ (M^+): 382.2901. Found: 382.2903.

Ethyl (2*Z*)- and (2*E*)-7-(Tetrahydropyranyloxy)-2-(trimethylsilylmethyl)-2-heptenoates (7a and 8a) According to the procedure of Hoffmann,[11,16] 60% sodium hydride (0.897 g, 22.4 mmol) was added to a solution of triethyl phosphonoacetate (4.05 ml, 20.4 mmol) in dry DME (20 ml) at 0 °C. The mixture was stirred at room temperature for 0.5 h, then a solution of iodomethyltrimethylsilane (4.8 g, 22.4 mmol) was added and the resulting mixture was stirred at 70 °C for 3 h, cooled to 0 °C and then treated with 60% sodium hydride (0.898 g, 22.4 mmol). The yellow suspension was stirred at room temperature for 1.5 h. A solution of the aldehyde (**4b**) (3.80 g, 20.4 mmol) in DME (10 ml) was added dropwise to the ylide. After being stirred at room temperature for 3 h, the reaction mixture was poured into dilute aqueous ammonium chloride and the aqueous phase was extracted with ether. The combined organic phase was washed with brine, and dried over $MgSO_4$. The ether was removed, and the resulting product was purified by column chromatography with 10% EtOAc–hexane, yielding a mixture of the α,β-unsaturated esters (**7a** and **8a**) (3.09 g, 44.5%) as a colorless oil. The ^{1}H-NMR spectrum of the mixture showed triplet signals due to the olefinic proton of **7a** [δ 6.60 (2/3H, $J=7$ Hz)] and **8a** [δ 5.65 (1/3H, $J=7$ Hz)].

Ethyl (2*Z*)- and (2*E*)-8-(Tetrahydropyranyloxy)-2-(trimethylsilylmethyl)-2-octenoates (7b and 8b) In the same way as described for **7a** and **8a**, the aldehyde (**4b**) (3.07 g, 16.8 mmol) was treated with the ylide [prepared from triethyl phosphonoacetate (3.04 ml, 15.3 mmol), iodomethyltrimethylsilane (3.6 g, 2.49 ml, 16.8 mmol) and 60% sodium hydride (1.34 g, 33.6 mmol) in dry DME (20 ml)] to yield a mixture of the α,β-unsaturated esters (**7b** and **8b**) (2.52 g, 46.3%) as a colorless oil. The ^{1}H-NMR spectrum of the mixture showed triplet signals due to the olefinic proton of **7b** [δ 6.58 (2/3H, $J=7$ Hz)] and **8b** [δ 5.62 (1/3H, $J=7$ Hz)].

(2*Z*)- and (2*E*)-Hydroxy Esters (9a and 10a) A solution of the mixture of **7a** and **8a** (2.70 g, 7.93 mmol) in ethanol (55 ml) containing PPTS (270 mg) was stirred at 55 °C for 3 h. After removal of the solvent, the residue was extracted with ether. The extract was washed with 10% $NaHCO_3$ and brine, and dried over $MgSO_4$. The resulting crude product was purified by column chromatography with 20% EtOAc–hexane to give a mixture of **9a** and **10a** (1.92 g, 93.6%) as a colorless oil. The ^{1}H-NMR spectrum of the mixture showed triplet signals assignable to the olefinic proton of **9a** [δ 6.60 (2/3H, $J=7$ Hz)] and **10a** [δ 5.57 (1/3H, $J=7$ Hz)].

(2*Z*)- and (2*E*)-Hydroxy Esters (9b and 10b) A solution of the mixture of **7b** and **8b** (2.52 g, 7.0 mmol) in ethanol (50 ml) was treated with PPTS (250 mg) at 55 °C for 3 h to give a mixture of **9b** and **10b** (1.74 g, 91.8%) as a colorless oil. The ^{1}H-NMR spectrum of the mixture showed triplet signals at δ 6.58 and 5.68 due to the olefinic protons of **9b** and **10b**, respectively.

Ethyl (2*Z*)- and (2*E*)-7-Formyl-2-(trimethylsilylmethyl)-2-heptenoates (11a and 12a) Swern oxidation of the mixture of the alcohols (**9a** and **10a**) (0.95 g, 3.67 mmol) was performed by a method similar to that described for the synthesis of **11a** using oxalyl chloride (0.35 ml, 4.03 mmol), dimethyl sulfoxide (0.57 ml, 8.07 mmol) and triethylamine (2.58 ml, 18.3 mmol). The crude material was purified by column chromatography with 15% EtOAc–hexane to give a mixture of the aldehydes (**11a** and **12a**) (827 mg, 87.9%) as a colorless oil. The mixture was separable by MPLC with 10% EtOAc–hexane to yield the (*E*)-isomer (**12a**) (198.7 mg, 21.1%) as a colorless oil and the (*Z*)-isomer (**11a**) (594.3 mg, 63.2%) also as a colorless oil. Data of **12a**: IR (neat) cm^{-1}: 1730, 1710, 1630, 1250, 1180, 850. ^{1}H-NMR δ: 0.06, (9H, s, $SiMe_3$), 1.37 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 1.79 (4H, m, 1′,5-H), 2.49 (4H, m, 4,6-H), 4.21 (2H, q, $J=7$ Hz, $COOCH_2$), 5.67 (1H, t, $J=7$ Hz, 3-H), 9.86 (1H, t, $J=1.7$ Hz, CHO). MS *m/z* (rel. intensity): 256 (M^+, 1), 241 (2.5), 211 (2), 200 (6), 185 (12), 157 (3), 129 (2), 109 (10), 93 (12), 81 (24), 75 (38), 73 (100), 45 (30). High-resolution MS Calcd for $C_{13}H_{24}O_3Si$ (M^+): 256.1493. Found: 256.1489.

Ethyl (2*Z*)- and (2*E*)-7-Formyl-2-(trimethylsilylmethyl)-2-octenoates (11b and 12b) Swern oxidation of the mixture of the alcohols (**9b** and **10b**) (814 mg, 3.0 mmol) was performed by the same method as described above, using oxalyl chloride (0.27 ml, 3.3 mmol), dimethyl sulfoxide (0.47 ml, 6.6 mmol) and triethylamine (2.1 ml, 15 mmol) to give a mixture of the aldehydes (**11b** and **12b**) (718 mg, 88.9%) as a colorless oil. The mixture was separated by MPLC with 10% EtOAc–hexane to give the (*E*)-isomer (**12b**) (122.6 mg, 15.2%) as a colorless oil, and the (*Z*)-isomer (**11b**) (470.5 mg, 58.2%) also as a colorless oil. Data of **12b**: IR (neat) cm^{-1}: 1730, 1710, 1630, 1250, 1180, 850. ^{1}H-NMR δ: 0.03 (9H, s, $SiMe_3$), 1.36 (3H, t, $J=7$ Hz, $COOCH_2C\underline{H}_3$), 1.49—1.90 (6H, m, 1′, 5,6-H), 2.46 (4H, m, 4,7-H), 4.22 (2H, q, $J=7$ Hz, $COOCH_2$), 5.67 (1H, t, $J=7$ Hz, 3-H), 9.86 (1H, t, $J=1.7$ Hz, CHO). MS *m/z* (rel. intensity): 270 (M^+, 2), 255 (6), 185 (43), 157 (8), 95 (16), 73 (100), 45 (16). High-resolution MS Calcd for $C_{14}H_{26}O_3Si$ (M^+): 270.1650. Found: 270.1653.

General Procedure for Cyclization Reaction with a Lewis Acid An

ω-formylated allylsilane (**11a**, **b**, **c**, **d** and **e**) (0.2 mmol) was dissolved in anhydrous CH_2Cl_2 (0.1 or 0.01 M concentration). A Lewis acid ($TiCl_4$ or BF_3 etherate) was added to the resulting solution. The reaction mixture was stirred, and the reaction was monitored by TLC. The reaction was quenched with 1 N NaOH and the mixture was diluted with CH_2Cl_2. The organic phase was washed with water and brine, and dried over $MgSO_4$. The crude product was purified by MPLC or preparative TLC by 20% EtOAc–hexane, affording hydroxy esters (**13a**, **b** and **14b**), lactone (**16b**), dimer (**15a**) and/or aldol adducts (**18a—e**). The results are summarized in Tables I, II and III. Data of **13a**: IR (neat) cm^{-1}: 3400, 1710, 1625. ^{1}H-NMR δ: 1.34 (3H, t, J=7 Hz, $COOCH_2C\underline{H}_3$), 2.75 (2H, q, J=7 Hz, 2-H), 3.10 (1H, s, OH), 4.01 (1H, br q, J=7 Hz, 1-H), 4.27 (2H, q, J=7 Hz, $COOC\underline{H}_2$), 5.64 (1H, dd, J=1.0, 0.5 Hz, olefinic H), 6.23 (1H, t, J=1.0 Hz, olefinic H). ^{13}C-NMR δ: 14.16 (q, C-10), 22.82 (t, C-4), 29.89 (t, C-3), 34.46 (t, C-5), 50.90 (d, C-2), 61.02 (t, C-9), 77.98 (d, C-1), 123.32 (t, C-8), 142.22 (s, C-6), 168.37 (s, C-6). MS m/z (rel. intensity): 184 (M^+, 2), 166 (M^+-H_2O, 12), 155 (17), 138 (70), 110 (42), 109 (100), 82 (50), 81 (52). High-resolution MS Calcd for $C_{10}H_{16}O_3$ (M^+): 184.1097. Found: 184.1073. Data of **15a** (oil): IR (neat) cm^{-1}: 1715, 1630, 1260, 1180, 1145. ^{1}H-NMR δ: 1.29 (6H, t, J=7 Hz, $COOCH_2C\underline{H}_3$), 2.85 (2H, q, J=7 Hz, 2,2′-H), 3.90 (2H, m, $w_{h/2}$=12 Hz, 1,1′-H), 4.18 (4H, q, J=7 Hz, $COOC\underline{H}_2$), 5.50 (2H, br t, J=1 Hz, olefinic H), 6.10 (2H, d, J=1 Hz, olefinic H). MS m/z (rel. intensity): 350 (M^+, 0.1), 304 (1), 183 (60), 167 (100), 121 (43), 93 (37). Data of **13b** (oil): IR (neat) cm^{-1}: 3500, 1710, 1630, 1275, 1140. ^{1}H-NMR δ: 1.32 (3H, t, J=7 Hz, $COOCH_2C\underline{H}_3$), 1.68 (1H, s, OH), 2.76 (1H, br d, J=12 Hz, 2-H), 4.01 (1H, br, $w_{h/2}$=5 Hz, 1-H), 4.22 (2H, q, J=7 Hz, $COOC\underline{H}_2$), 5.63 (1H, t, J=1.5 Hz, olefinic H), 6.34 (1H, d, J=1.5 Hz, olefinic H). MS m/z: (rel. intensity): 198 (M^+, 6), 180 (M^+-H_2O, 5), 170 (M^+-CO, 39), 152 (M^+-EtOH, 100), 124 ($M^+-HCOOEt$, 90), 95 (63), 67 (63), 29 (75). High-resolution MS Calcd for $C_{11}H_{18}O_3$ (M^+): 198.1255. Found: 198.1255. Data of **14b** (oil): IR (neat) cm^{-1}: 3400, 1710, 1630, 1270, 1235, 1150. ^{1}H-NMR δ: 1.34 (3H, t, J=7 Hz, $COOCH_2C\underline{H}_3$), 2.20 (1H, s, OH), 2.50 (1H, td, J=10, 3 Hz, 2-H), 3.57 (1H, td, J=10, 4 Hz, 1-H), 4.27 (2H, q, J=7 Hz, $COOC\underline{H}_2$), 5.69 (1H, t, J=1 Hz, olefinic H), 6.31 (1H, d, J=1 Hz, olefinic H). MS m/z (rel. intensity): 198 (M^+, 7), 180 (M^+-H_2O, 4), 170 (M^+-CO, 41), 152 (M^+-EtOH, 100), 124 ($M^+-HCOOEt$, 98), 95 (68), 67 (70), 29 (74). High-resolution MS Calcd for $C_{11}H_{18}O_3$ (M^+): 198.1255. Found: 198.1266. Data of **16b** (oil): IR (neat) cm^{-1}: 1760, 1665, 1265, 1125, 975, 965. ^{1}H-NMR δ: 3.04 (1H, m, $w_{h/2}$=12 Hz, 2-H), 4.57 (1H, q, J=6 Hz, 1-H), 5.55 (1H, d, J=3 Hz, olefinic H), 6.72 (1H, d, J=3 Hz, olefinic H). MS m/z (rel. intensity): 152 (M^+, 23), 124 (M^+-CO, 100), 95 (83), 67 (79), 39 (75). High-resolution MS Calcd for $C_9H_{12}O_2$ (M^+): 152.0836. Found: 152.0808. Data of **18a** (oil): IR (neat) cm^{-1}: 1700 (br), 1630, 1255, 1170, 1050, 850. ^{1}H-NMR δ: 1.30 (6H, t, J=7 Hz, $COOCH_2C\underline{H}_3$), 1.78, 1.80 (each 2H, s, CH_2TMS), 2.0—2.5 (8H, m, allylic H), 4.16, 4.17 (each 2H, q, J=7 Hz, $COOC\underline{H}_2$), 6.50 (3H, m, olefinic H), 9.36 (1H, s, CHO). Data of **18c** (oil): IR (neat) cm^{-1}: 1715, 1690, 1640, 1255, 1170, 1040, 840. ^{1}H-NMR (60 MHz) δ: 1.30 (6H, t, J=7 Hz, $COOCH_2C\underline{H}_3$), 1.80 (4H, s, CH_2TMS), 4.16 (4H, q, J=7 Hz, $COOC\underline{H}_2$), 6.50 (3H, m, olefinic H), 9.36 (1H, s, CHO). Data of **18d** (oil): IR (neat) cm^{-1}: 1710, 1690, 1640, 1250, 1175, 1040, 845. ^{1}H-NMR (60 MHz) δ: 1.30 (6H, t, J=7 Hz, $COOCH_2C\underline{H}_3$), 1.80 (4H, s, CH_2TMS), 4.16 (4H, q, J=7 Hz, $COOC\underline{H}_2$), 6.50 (3H, m, olefinic H), 9.36 (1H, s, CHO). Data of **18e** (oil): IR (neat) cm^{-1}: 1705, 1690, 1640, 1250, 1170, 1040, 845. ^{1}H-NMR (60 MHz) δ: 1.30 (6H, t, J=7 Hz, $COOCH_2C\underline{H}_3$), 1.80 (4H, s, CH_2TMS), 4.16 (4H, q, J=7 Hz, $COOC\underline{H}_2$), 6.50 (3H, m, olefinic H), 9.36 (1H, s, CHO).

Lactonization of 13a A benzene solution (3 ml) of **13a** (51 mg, 0.277 mmol) containing *p*-toluenesulfonic acid (57 mg, 0.3 mmol) was heated to reflux temperature for 1 h. The reaction mixture was diluted with benzene (30 ml), washed with 10% $NaHCO_3$ and brine, and dried over $MgSO_4$. The solvent was removed, and the resulting crude product was purified by preparative TLC using 25% EtOAc–hexane to give 31.7 mg (82.6%) of the *cis*-lactone (**16a**) as a colorless oil. IR (neat) cm^{-1}: 1760, 1655, 1265, 1145, 1105, 975. ^{1}H-NMR δ: 3.47 (1H, m, $w_{h/2}$=20 Hz, 2-H), 5.02 (1H, br t, J=5 Hz, 1-H), 5.70 (1H, d, J=3 Hz, olefinic H), 6.28 (1H, d, J=3 Hz, olefinic H). MS m/z (rel. intensity): 138 (M^+, 57), 109 (100), 95 (17), 81 (91). High-resolution MS Calcd for $C_8H_{10}O_2$ (M^+): 138.0679. Found: 138.0670.

Lactonization of 13b A benzene (2 ml) solution of **13b** (29 mg, 0.146 mmol) and *p*-toluenesulfonic acid (10 mg) was heated at reflux temperature for 1 h. Extraction followed by TLC purification afforded 21.0 mg (94.3%) of the *cis*-lactone (**16b**).

Lactonization of 14b A benzene solution of **14b** (22 mg, 0.11 mmol) and *p*-toluenesulfonic acid (8 mg) was heated for 1.5 h, affording 15.4 mg (91.1%) of the *trans*-lactone (**17b**) as colorless crystals. Recrystallization from hexane gave colorless needles, mp 40—41 °C. IR (KBr) cm^{-1}: 1755, 1670, 1255, 1130, 1020, 985. ^{1}H-NMR δ: 3.73 (1H, td, J=11, 4 Hz, 1-H), 5.42 (1H, d, J=3 Hz, olefinic H), 6.10 (1H, d, J=3 Hz, olefinic H). MS m/z (rel. intensity): 152 (M^+, 12), 124 (M^+-CO, 99), 96 (51), 95 (84), 67 (79), 39 (95). High-resolution MS Calcd for $C_9H_{12}O_2$ (M^+): 152.0836. Found: 152.0823. *Anal.* Calcd for $C_9H_{12}O_2$: C, 71.02; H, 7.95. Found: C, 71.07; H, 7.95.

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