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Regioselective Tandem Ring Closing/Cross Metathesis of 1,5-Hexadien-3-ol Derivatives: Application to the Total Synthesis of Rugulactone

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A tandem ring-closing metathesis/cross-metathesis procedure was devised for the synthesis of various pyrones. The reaction occurred with high regioselectivity and *E* stereocontrol of the lateral unsaturated chain. This process was applied to the synthesis of rugulactone, an inhibitor of the nuclear factor NF-κB according to a four-step sequence.

Introduction

A large number of 5,6-dihydropyrones isolated from *Annonaceae* species like goniothalamin (**1**) exhibit potent antitumor activities (Figure 1).[1] They usually possess a styryl chain attached to the 6-position and have attracted the efforts of chemists over the past two decades.[2,3] Pyrones substituted by an allyl chain at this position have been more rarely isolated from nature. Among them, tuberolactone (**2**) identified as a trace in tuberose oil plays a major role in fragrance and flavor industries.[4,5]

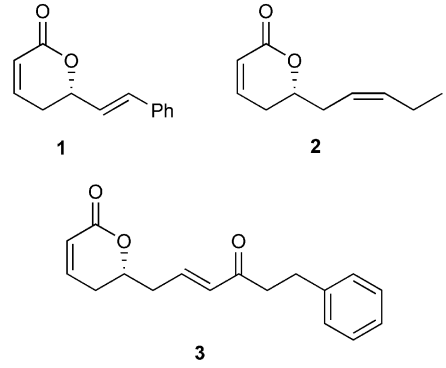

Figure 1. Naturally occurring pyrones.

Recently, rugulactone (**3**) was extracted by Cardellina et al. from the plant *Cryptocaria rugulosa*.[6] This compound, produced in very small amounts (7 mg isolated from 725 g of the dried leaves), is an efficient inhibitor of the nuclear factor (NK-κB) activation pathway. This factor has a major biological role. Bound to discrete DNA sequences, it can initiate gene expressions that are implicated in major diseases like cancer and diabetes. Therefore, the synthesis of rugulactone and related pyrones appears as an interesting subject of research. Since the discovery of efficient catalysts,[7] ring-closing metathesis (RCM) is nowadays one the best methods to prepare pyrones. To date, three syntheses of **3** have been reported, respectively, by the groups of Yadav, Venkateswarlu, and Fadnavis.[8] For two of them, the pyrone subunit was built by a RCM reaction, whereas the lateral chain was functionalized by a Wittig reaction and a cross-metathesis process, respectively.[8a,8b] It should be noted that a one-pot hydrosilylation/RCM/protodesilylation sequence was earlier devised by Cossy et al. to prepare a related structure.[9]

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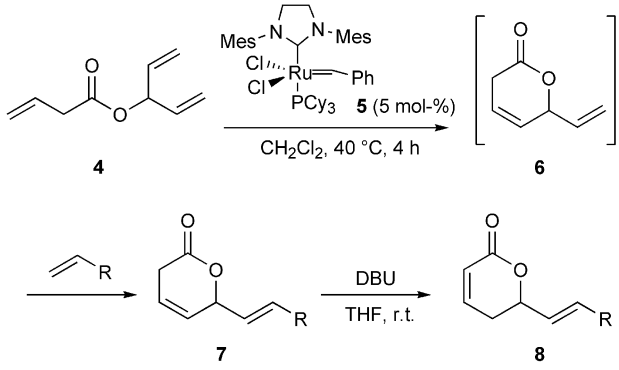
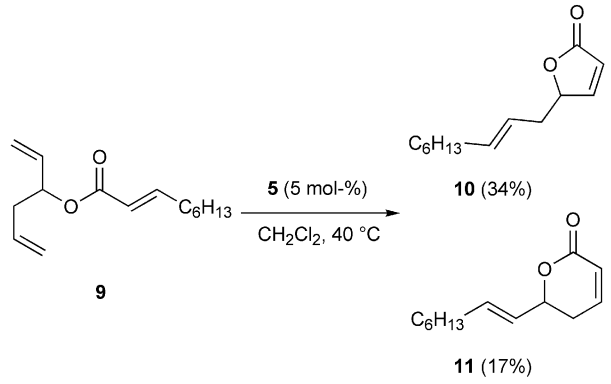
Results and Discussion

In connection with our interest in the synthesis of 6-alkenylpyrones, we described some years ago, a tandem RCM/cross metathesis (CM) sequence from symmetric 3-*O*-(1,4-pentadienyl) vinyl acetate **4** promoted by Grubbs' ruthenium catalyst **5** (Scheme 1).[10,11] This strategy, which is complementary to ring rearrangement metatheses (RRM),[12] was later applied to unsaturated ethers to deliver functionalized dihydropyrans.[13]



Scheme 1. Tandem ring closing/cross metathesis of ester **4**.

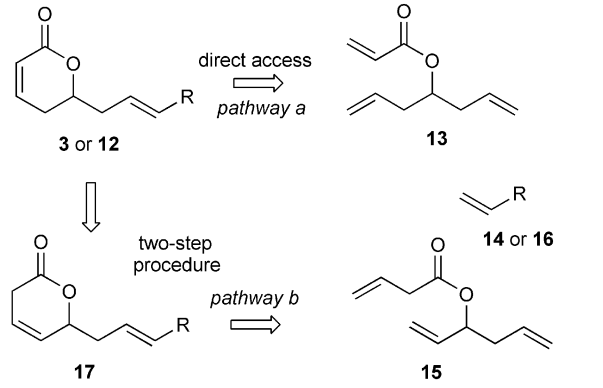
To expand the scope of this tandem process, we also reported the reaction of 3-*O*-(1,5-hexadienyl) α,β-unsaturated ester **9**, which delivered a mixture of butenolide **10** and hexenolide **11** in moderate yields (Scheme 2). While the work described in the present publication was in progress, Quinn and co-workers reported an efficient synthesis of a naturally occurring pyrone on the basis of, first, RCM of a substituted 3-*O*-(1,5-hexadienyl) 3-butenoate and, second, after addition of a chosen alkene, by cross metathesis on the lateral chain.[14] In that case, Hoveyda–Grubbs catalyst **5b** was however required to prevent additional isomerization of the newly created internal double bond. Disappointingly, the tandem procedure was unsuccessful, leading mainly to a product resulting from cross metatheses between the less-substituted double bonds.



Scheme 2. RCM and alkenyl transfer from 3-*O*-(1,5-hexadienyl) ester **9**.

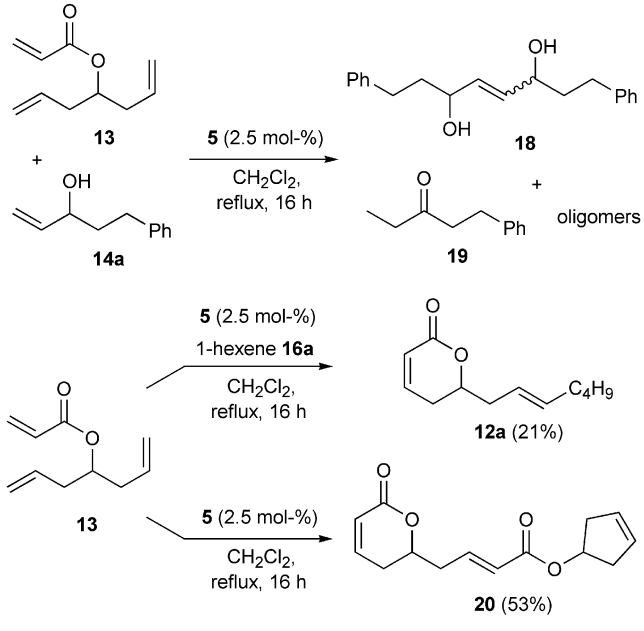
Having in mind all these results, we have investigated the synthesis of **3** and parent compounds **12** and considered their synthesis according to two disconnections summarized in Scheme 3. The first one was based on tandem RCM/CM starting from acrylate **13**, readily prepared from commercially available 1,6-heptadien-4-ol (pathway a). Although the competitive formation of a cyclopentene derivative could not be totally excluded by RCM of the two terminal double bonds fixed on the alkoxy group,[15] it was expected that in presence of an alkene partner, the tandem RCM/CM procedure could take place − even starting from a deactivated acrylate − leading directly to the core structure of **3** or analogues **12**. The second strategy (pathway b), which is similar to the process recently reported by Quinn, consisted in using less-deactivated ester **15**, prepared from vinylacetic acid and unsymmetrical 1,5-hexadien-3-ol. In this approach, RCM of the two terminal alkenes fixed on the alkoxy group leading to a cyclobutene derivative could be excluded for steric reasons. Otherwise, the reaction between the unsaturation fixed on the acid chain could take place more favorably with the vinyl group to form a 6-allylpyrone structure compared to the reaction involving the allyl rest leading to a 7-vinyl caprolactone.[14,16,17]

Treatment of **13** with alcohol **14a** in the presence of Grubbs type II catalyst **5** afforded dimer structure **18**, ketone **19**[18] resulting from the isomerization of the terminal double bond[19] and further reketonization, and also



Scheme 3. Retrosynthetic analyses for **3** and related 6-allyl hexenolides **12**.

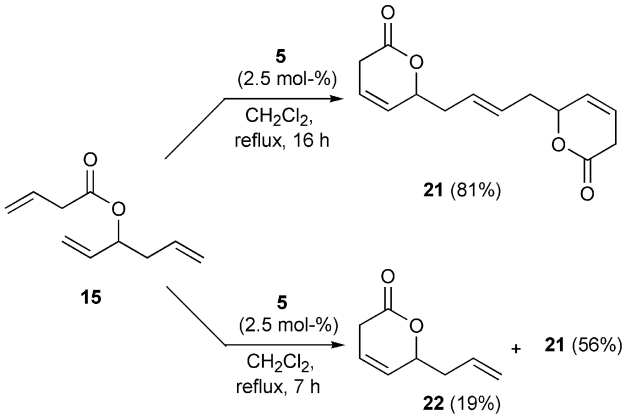
intractable oligomeric forms instead of the expected lactone (Scheme 4). The same procedure was carried out with simpler alkene 1-hexene (**16a**). Interestingly, the tandem reaction took place and delivered lactone **12a**, albeit in a very disappointing yield. As recently pointed out by Quinn et al., the presence of a hydroxy group close to the double bond seems to be detrimental to the efficiency of the reaction.[14] The reactivity of **13** in the absence of any alkene partner was also investigated. In that case, new structure **20** was isolated, resulting from a cascade reaction involving two double ring closures and a cross metathesis. Interestingly, when **20** was placed under classic metathetical conditions and in the presence of alcohol **14a**, compounds **18** and **19** were solely obtained as new products of the reaction, demonstrating the robustness of the dimeric structure toward cross-metathesis reactions.



Scheme 4. Tandem RCM/CM starting from ester **13**.

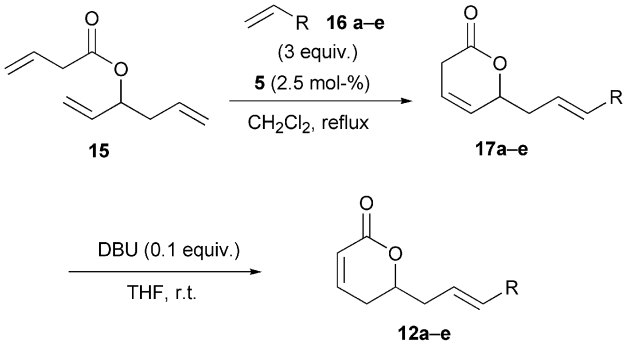
The first strategy gave disappointing results, and the reactivity of unsymmetrical ester **15** was thus next considered. Placed in the presence of catalyst **5** (2.5 mol-%) and in the

absence of any alkene as reactant, **15** afforded a new dimeric structure identified as **21** in high yield (Scheme 5).



Scheme 5. RCM/dimerization of ester **15**.

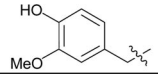
At this stage, it was anticipated that RCM proceeded first before the dimerization; effectively, when the above reaction was stopped after only 7 h of heating, **21** was isolated in 59% yield, although 6-allylpyrone **22** was obtained in only 19%. The selective formation of hexenolides confirmed the hypothesis concerning the regioselectivity for the ring closure of substrate **15**. This ester was next placed in the presence of different alkenes **16a**–**e** under dilute conditions and in the presence of catalyst **5**. To our delight, the RCM/CM process occurred nicely in a majority of cases and delivered lactones **17** in good yields (Scheme 6). Whatever, the nature of the alkene, including phenol derivative eugenol **16e**, the tandem procedure delivered expected pyrones **17a**–**e** in 60–70% yield (Table 1). In each case, the *E* configuration of the double bond on the lateral chain was attributed by measurement of the coupling constant between the two olefinic protons. The β,γ-unsaturated pyrones were efficiently reconjugated into hexenolides **3b**–**f** by treatment at room temperature with a catalytic amount of DBU (0.1 equiv.), (Scheme 7).[20] Interestingly, pyrone **18g** underwent two C=C bond migrations in the same pot to afford compound **3g′** in 49% yield.



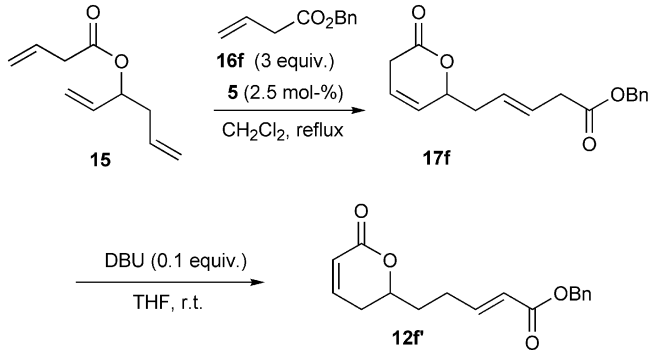
Scheme 6. Synthesis of pyrones **12a**–**e** by RCM/CM from ester **15**.

While the overall process appeared efficient with a large number of alkenes, we next considered the synthesis of rugulactone from ester **15**. As demonstrated above with ester **13**, the reactivity of alkene **14a** seemed problematic under

Table 1. RCM/CM between ester **15** and elkenes **16a**–**e**.

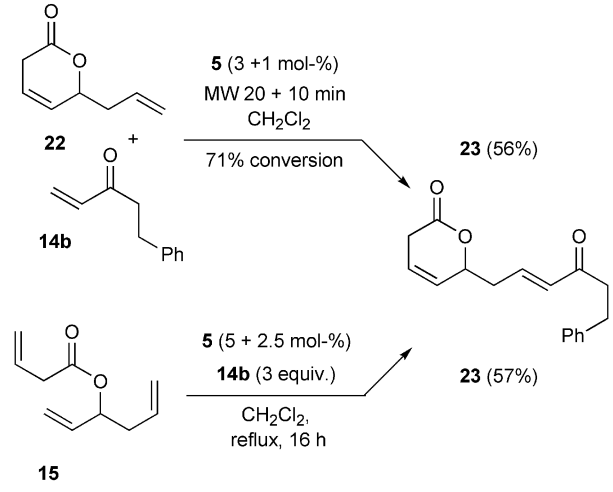
Entry	16	R	17, % yield[a]	12, % yield
1	**16a**	C_4H_9	**17a**, 61	**12a**, 70
2	**16b**	C_3H_7	**17b**, 60	**12b**, 80
4	**16c**	Ph	**17c**, 62	**12c**, 67
5	**16d**	$(CH_3)_2CHCH_2$	**17d**, 61	**12d**, 65
6	**16e**		**17e**, 70	**12e**, 52

[a] Isolated yield.



Scheme 7. Tandem RCM/CM process from ester **15** with alkene **16f**.

metathesis conditions, leading promptly to dimerization[21] or double-bond isomerization. Therefore, enone **14b** was chosen as partner for the RCM/CM process. Cross-coupling of lactone **22** with **14b** (3 equiv.) was investigated under microwave (MW) activation.[22] After a reaction time of only 30 min, a conversion of 71% was noticed and lactone **23**, the β,γ-unsaturated isomer of **3**, was isolated in 56% yield (Scheme 8).

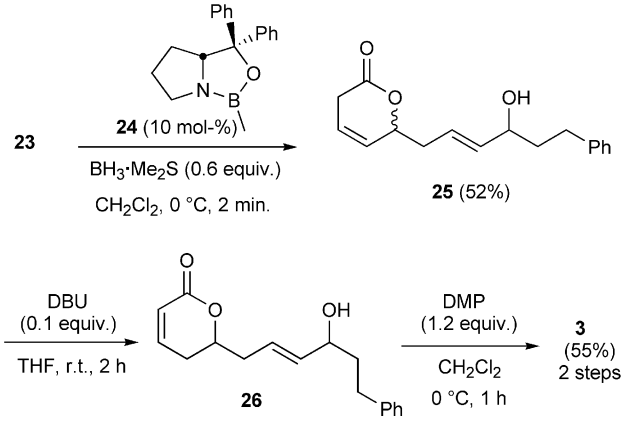


Scheme 8. RCM/CM of ester **15** in the presence of enone **14b**.

The tandem procedure was tested with **15** under conventional heating and afforded **23** in a similar yield and lactone **22** as a minor compound (25%). Unfortunately, attempts to convert **23** into rugulactone by treatment with DBU[20] led to the decomposition of the material. This inefficiency was

attributed to the competitive abstraction of the proton at the γ-position of the keto group, followed by further elimination to a linear trienic structure. An alternative isomerization of the internal double bond based on the in situ formation of ruthenium hydride was tested.[23] Unfortunately, this procedure directly combined with the formation of compound **23** furnished a complex mixture of compounds.

To prevent the side reaction observed during the basic reconjugation, the keto group of **23** had to be selectively reduced. Corey–Bakshi–Shibata conditions[24] were chosen for two purposes. At first, the keto group could be smoothly reduced in the presence of a lactone moiety,[25] and second, this asymmetric process could furnish the corresponding alcohols as an enriched mixture of diastereomers. Nevertheless, to avoid the reduction of the pyrones, a short reaction time (only 2 min) was required. Resulting hydroxyactones **25** were thus obtained in a moderate 52% yield and unfortunately as an inseparable mixture of diastereomers. To complete the synthesis, the mixture was finally treated with Dess–Martin periodinane[26] to deliver rugulactone (**3**) in 55% yield (Scheme 9).



Scheme 9. Completion of the synthesis of rugulactone (**3**).

Conclusions

In conclusion, a regioselective tandem RCM/CM procedure was developed for rapid access to functionalized pyrones. This sequence was successfully applied to the four-step synthesis of (±)-rugulactone from readily available starting materials in a 16% overall yield.

Experimental Section

General: All manipulations with air-sensitive reagents were carried out under a dry argon atmosphere by using standard Schlenk techniques. Solvents were purified according to standard procedures: THF and ether with sodium/benzophenone and dichloromethane with CaH_2. Column flash chromatography was performed by using Kieselgel 60 (230–400 mesh). ^1H and ^{13}C NMR spectra were recorded at 300 and 75 MHz, respectively, in $CDCl_3$; chemical shifts (δ) are referenced to tetramethylsilane. FTIR spectra were measured with KBr plates.

4-Hepta-1,6-dienyl Acrylate (13): To a solution of 1,6-heptadien-4-ol (0.50 mL, 3.85 mmol) in dichloromethane (19 mL) was added triethylamine (1.18 mL, 8.47 mmol) and DMAP (24 mg, 0.19 mmol). After cooling to 0 °C, acryloyl chloride (0.63 mL, 7.70 mmol) was added dropwise. The resulting mixture was stirred at room temperature for 4 h. After hydrolysis with a saturated aqueous solution of ammonium chloride, the aqueous layer was extracted with dichloromethane. The organic layer was successively washed with water and brine and dried with $MgSO_4$. After filtration, the solvent was removed by concentration, and the mixture was purified by flash chromatography on silica (EtOAc/hexanes, 5:95). Ester **13** (281 mg, 1.69 mmol) was obtained as a colorless oil. Yield: 44%. ^1H NMR: δ = 2.33–2.38 (m, 4 H, CH_2=CH-CH_2-), 5.02–5.11 (m, 5 H, CH_2=CH-CH_2- and -C*H*-O), 5.69–5.80 (m, 2 H, CH_2=C*H*-CH_2-), 5.80 (dd, J = 10.3, 1.1 Hz, 1 H, CH_2=CH-CO, H_{cis}), 6.09 (dd, J = 17.3, 10.3 Hz, 1 H, CH_2=C*H*-CO), 6.38 (dd, J = 17.3, 1.1 Hz, 1 H, 1 H, CH_2=CH-CO, H_{trans}) ppm. ^{13}C NMR: δ = 37.8 (CH_2), 72.3 (*C*-O), 117.7 (2 CH_2=CH), 128.6 (CH_2=*CH*), 130.2 (CH_2=CH), 133.2 (2 CH_2=*CH*), 165.3 (CO_2) ppm.

3-(1,5-Hexadienyl) But-3-enoate (15): To a solution of 1,5-hexadien-3-ol (1.13 mL, 10.0 mmol) in dichloromethane (50 mL) cooled to 0 °C was successively added DCC (2.27 g, 11.0 mmol), DMAP (0.367 g, 3.0 mmol), and vinylacetic acid (0.94 mL, 11.0 mmol). After 15 min, the solution was warmed to room temperature and stirred overnight. The resulting suspension was concentrated under vacuum. After addition of ethyl ether (20 mL), urea was filtered off. The resulting mixture was purified by flash chromatography on silica (hexanes/EtOAc, 95:5) to give **15** (1.535 g, 9.24 mmol). Yield: 92%. ^1H NMR: δ = 2.39 (t, J = 6.6 Hz, 2 H), 3.10 (dt, J = 6.9, 1.4 Hz, 2 H), 5.06–5.22 (m, 5 H), 5.27–5.35 (m, 2 H), 5.66–5.99 (m, 3 H) ppm. ^{13}C NMR: δ = 38.6 (CH_2), 39.1 (CH_2), 73.5 (*CH*-O), 116.6 (CH=CH_2), 117.8 (CH=CH_2), 118.1 (CH=CH_2), 130.2 (*CH*=CH_2), 132.9 (*CH*=CH_2), 135.7 (*CH*=CH_2), 170.1 (CO_2) ppm. IR: $\tilde{\nu}$ = 919, 989, 1100, 1171, 1251, 1318, 1426, 1643, 1739, 2930, 2984, 3082 cm^{-1}.

Tandem RCM/Cross Metathesis with Alkene 14a: A solution of ester **13** (1 mmol) and alcohol **14a** in dichloromethane (100 mL) was deoxygenated by bubbling an argon stream through the solution for 10 min. Grubbs type II catalyst **5** (21 mg, 0.025 mmol) was added in one portion, and the resulting homogeneous solution was heated for 16 h. After concentration, diol **18** and ketone **19** were isolated after flash chromatography on silica (EtOAc/hexanes, 20:80).

1,8-Diphenyl-oct-4-en-3,6-diol (18): Brown oil. Data for diastereomer 1: ^1H NMR: δ = 1.81–1.90 (m, 4 H), 2.67–2.75 (m, 4 H), 4.14 (m, 2 H), 5.71–5.73 (m, 2 H), 7.18–7.20 (m, 6 H), 7.27–7.28 (m, 4 H, 4 H) ppm. ^{13}C NMR: δ = 31.8 (CH_2), 38.8 (CH_2), 71.6 (CH), 126.0 (CH_{ar}), 128.6 (CH_{ar}), 133.7 (CH_{ar}), 141.8 (C) ppm. Data for diastereomer 2: ^1H NMR: δ = 1.50–2.00 (m, 4 H), 2.62–2.79 (m, 4 H), 4.14 (m, 2 H), 5.71–5.73 (m, 2 H), 7.18–7.20 (m, 6 H), 7.27–7.28 (m, 4 H, 4 H) ppm. ^{13}C NMR: δ = 31.8 (CH_2), 38.8 (CH_2), 71.7 (CH), 126.0 (CH_{ar}), 128.6 (CH_{ar}), 133.9 (CH_{ar}), 141.8 (C) ppm. IR: $\tilde{\nu}$ = 698, 747, 1030, 1056, 1100, 1453, 1495, 1602, 2858, 2924, 3025, 3100–3500 cm^{-1}. MS (CI): *m*/*z* (%) = 280 (18) $[M]^+$, 279, 261.

Reactivity of Ester 13 in the Absence of Alkene

Cyclopent-3-enyl 4-(6-Oxo-3,6-dihydro-2*H*-pyran-2-yl)-but-2-enoate (20): Ester **13** (183 mg, 1.10 mmol) was dissolved in dichloromethane (100 mL). Argon was bubbled through the solution for 10 min. Grubbs type II catalyst **5** (23 mg, 0.03 mmol) was added to the solution, and the homogeneous mixture was heated under reflux

overnight. After concentration, the crude mixture was purified by flash chromatography on silica (EtOAc/hexanes, 50:50). Ester **20** (72 mg, 0.26 mmol) was isolated as a light brown oil. Yield: 53%. ^{1}H NMR: δ = 2.34–2.40 (m, 4 H, CH_2-CH-CH_2), 2.45–2.69 (m, 2 H, CH_2-CH-), 2.72–2.80 (m, 2 H, CH_2-CH-), 4.56 (br. quint., J = 7.0 Hz, 1 H, CH_2-CH-CH_2), 5.40–5.45 (m, 1 H, CH_2-CH-CH_2), 5.72 (br. s, 2 H, CH_2-CH=CH-CH_2), 5.93 (dt, J = 15.8, 1.4 Hz, 1 H, CH_2-CH=CH), 6.04 (dt, J = 9.7, 1.7 Hz, 1 H, CH=CH-CO), 6.85–6.91 (m, 2 H, CH=CH) ppm. ^{13}C NMR: δ = 28.9 (CH_2), 37.3 (CH_2), 39.7 (2 CH_2), 74.3 (O-CH), 76.1 (O-CH), 121.4 (CH=), 125.3 (CH=), 128.3 (CH=), 141.8 (CH=), 144.7 (CH=), 163.8 (CO_2), 165.8 (CO_2) ppm. IR: $\tilde{\nu}$ = 735, 815, 1045, 1188, 1248, 1316, 1387, 1426, 1657, 1716, 2852, 2923, 3061 cm^{-1}. HRMS: calcd. for $C_{14}H_{16}O_4$ [M + H]$^+$ 249.1127; found 249.1126.

Reactivity of Ester 15

Reactivity in the Absence of Alkene

Conditions A: A solution of ester **15** (183 mg, 1.10 mmol) dissolved into dichloromethane (100 mL) was deoxygenated by bubbling with a stream of argon for 10 min. Grubbs type II catalyst (23 mg, 0.03 mmol) was added at once, and the resulting solution was heated overnight. After concentration, the crude mixture was purified by flash chromatography on silica (hexanes/EtOAc, 50:50) affording dimer **21** (111 mg, 0.45 mmol). Yield: 81%.

Conditions B: A solution of ester **15** (500 mg, 3.01 mmol) dissolved into dichloromethane (300 mL) was deoxygenated by bubbling with a stream of argon for 10 min. Grubbs type II catalyst (64 mg, 0.07 mmol) was added at once, and the resulting solution was heated for only 7 h. After concentration, the crude mixture was purified by flash chromatography on silica (hexanes/EtOAc, 80:20 then 50:50) affording dimer **21** (219 mg, 0.88 mmol) in 59% yield. Lactone **22** (80 mg, 0.58 mmol) was isolated as a side product in 19% yield.

Dimeric Structure 21: Brown oil. ^{1}H NMR: δ = 2.46–2.50 (m, 4 H, CH_2-CH-O), 3.04–3.05 (m, 4 H, CH_2-CO_2), 4.99–5.02 (m, 2 H, CH-O), 5.58–5.60 (m, 2 H, -CH=), 5.79–5.86 (m, 4 H, -CH=CH-) ppm. ^{13}C NMR: δ = 29.9 (2 -CH_2-CO_2), 38.6 (2 -CH_2-CH-O), 78.8 (2 -CH-O), 122.0 (2 =C-H), 125.5 (2 =C-H), 128.2 (2 =C-H), 168.8 (2 -CO_2-) ppm. IR: $\tilde{\nu}$ = 738, 1071, 1265, 1386, 1735, 2846, 2919, 3058 cm^{-1}. HRMS (CI): calcd. for $C_{14}H_{16}O_4$ [M + H]$^+$ 249.1127; found 249.1128.

6-Allyl-3,6-dihydro-pyran-2-one (22): ^{1}H NMR: δ = 2.51 (t, J = 5.8 Hz, 2 H, CH_2-CH-O), 3.03–3.05 (m, 2 H, CH_2-CO_2), 5.02–5.05 (m, 1 H, CH-O), 5.15–5.21 (m, 2 H, CH_2=CH-), 5.73–5.79 (m, 1 H, CH_2=CH-), 5.81–5.89 (m, 2 H, -CH=CH-) ppm. ^{13}C NMR: δ = 29.9 (-CH_2-CO_2), 39.6 (-CH_2-CH-O), 78.2 (-CH-O), 119.3 (-CH=CH_2), 121.8 (-CH_2-CH=), 125.6 (=CH-CHO-), 131.5 (CH_2-CH=), 168.7 (CO_2), 121.8 (CH, C3), 125.6 (CH, C4), 131.5 (CH, C7), 168.7 (C, C1) ppm. IR: $\tilde{\nu}$ = 700, 736, 1074, 1262, 1454, 1714, 2854, 2925 cm^{-1}. HRMS: calcd. for $C_8H_{11}O_2$ [M + H]$^+$ 139.0759; found 139.0759.

General Procedure for Tandem RCM/CM Reactions between Ester 15 and Alkenes 16a–f: Ester **15** (1 mmol) and alkene **16** (3 mmol) were dissolved in dichloromethane (100 mL). After bubbling with an argon stream for 10 min, Grubbs type II catalyst (0.025 mmol) was directly added, and the resulting solution was heated to reflux until complete disappearance of ester **17** (TLC control). After concentration under vacuum, corresponding pyrone **18** was purified by flash chromatography on silica.

6-Hept-2-enyl-3,6-dihydropyran-2-one (17a): Eluent: hexanes/EtOAc, 80:20. Colorless oil. Yield: 61% (71 mg, 0.37 mmol). ^{1}H NMR: δ = 0.88 (t, J = 7.1 Hz, 3 H, CH_3), 1.25–1.35 (m, 4 H, CH_2-CH_2), 2.00 (br. q, J = 7.3 Hz, 2 H, =CH-CH_2), 2.44 (t, J = 6.8 Hz, 2 H, OCH-CH_2), 3.02–3.03 (m, 2 H, CH_2-CO_2), 4.96–5.00 (m, 1 H, CH-O), 5.35–5.42 (m, 1 H, CH=), 5.53–5.63 (m, 1 H, CH=), 5.85 (br. s, 2 H, -CH=CH-) ppm. ^{13}C NMR: δ = 13.8 (CH_3), 22.1 (CH_2), 30.0 (CH_2-CO_2), 31.3 (CH_2), 32.3 (=CH-CH_2-), 38.6 (-CH_2-CH-O), 79.3 (-CH-O), 121.6 (-CH=), 122.6 (-CH=), 125.9 (-CH=), 135.9 (-CH=), 169.0 (CO_2) ppm. IR: $\tilde{\nu}$ = 739, 1265, 1376, 1735, 2935, 3028 cm^{-1}. HRMS: calcd. for $C_{12}H_{19}O_2$ [M + H]$^+$ 194.1307; found 194.1307.

6-Hex-2-enyl-3,6-dihydropyran-2-one (17b): Eluent: hexanes/EtOAc, 80:20. Colorless oil. Yield: 60% (97 mg, 0.21 mmol) ^{1}H NMR: δ = 0.87 (t, J = 7.3 Hz, 3 H, CH_3), 1.37 (sext., J = 7.3 Hz, 2 H, CH_2-CH_3), 1.98 (br. q, J = 7.0 Hz, 2 H, =CH-CH_2), 2.44 (t, J = 6.7 Hz, 2 H, CH_2-CH=), 3.02–3.03 (m, 2 H, CH_2-CO_2), 4.96–5.00 (m, 1 H, CH-O), 5.33–5.43 (m, 1 H, CH_2-CH=), 5.53–5.62 (m, 1 H, CH_2-CH=), 5.84 (br. s, 2 H, -CH=CH-) ppm. ^{13}C NMR: δ = 13.3 (CH_3), 22.3 (CH_2-CH_3), 30.0 (CH_2-CO_2), 34.7 (CH_2-CH_2), 38.6 (CH_2-CH=), 79.3 (CH-O), 121.6 (CH=), 122.8 (CH=), 125.9 (CH=), 135.7 (CH=), 169.0 (CO_2) ppm. IR: $\tilde{\nu}$ = 738, 1268, 1377, 1733, 2930, 3024 cm^{-1}. HRMS: calcd. for $C_{11}H_{17}O_2$ [M + H]$^+$ 181.1229; found 181.1229.

6-(Cinnamyl)-3,6-dihydropyran-2-one (17c): Eluent: hexanes/EtOAc, 80:20 then 50:50. Colorless oil. Yield: 62% (120 mg, 0.56 mmol). ^{1}H NMR: δ = 2.64–2.70 (m, 2 H, CH_2-CH=), 3.02–3.04 (m, 2 H, CH_2-CO_2), 5.09–5.13 (m, 1 H, CH-O), 5.89 (br. s, 2 H, CH=CH), 6.18 (dt, J = 16.0, 7.1 Hz, 1 H, CH_2-CH=), 6.51 (d, J = 16.0 Hz, 1 H, =CH-Ph), 7.22–7.32 (m, 5 H, CH_{ar}) ppm. ^{13}C NMR: δ = 29.9 (CH_2-CO_2), 38.8 (CH_2), 78.9 (CH-O), 122.0 (CH), 122.9 (CH), 125.6 (CH), 126.1 (2 CH), 127.4 (CH), 128.4 (2 CH), 134.2 (CH), 136.8 (C), 168.7 (CO_2) ppm. IR: $\tilde{\nu}$ = 693, 746, 968, 1070, 1156, 1225, 1380, 1738, 2922, 3027 cm^{-1}. HRMS: calcd. for $C_{14}H_{14}O_2$ [M]$^{+\cdot}$ 214.0994; found 214.0992.

6-(5-Methylhex-2-enyl)-3,6-dihydropyran-2-one (17d): Eluent: hexanes/EtOAc, 80:20. Colorless oil. Yield: 61% (107 mg, 0.55 mmol). ^{1}H NMR: δ = 0.86 (d, J = 6.6 Hz, 6 H, 2 CH_3), 1.57–1.64 [m, 1 H, CH(CH_3)$_2$], 1.86–1.93 (m, 2 H, =CH-CH_2), 2.46 (t, J = 6.3 Hz, 2 H, CH_2-CH=), 3.02–3.03 (m, 2 H, CH_2-CO_2), 4.99–5.01 (m, 1 H, CH-O), 5.32–5.41 (m, 1 H, =CH), 5.51–5.61 (m, 1 H, =CH), 5.84 (br. s, 2 H, 2 = CH) ppm. ^{13}C NMR: δ = 22.2 (CH_3), 22.3 (CH_3), 28.3 (CH), 30.0 (CH_2-CO_2), 38.7 (CH_2-CH=), 42.0 (CH=CH_2), 79.4 (CH-O), 121.7 (CH), 123.8 (CH), 126.0 (CH), 134.6 (CH), 169.0 (CO_2) ppm. IR: $\tilde{\nu}$ = 701, 972, 1069, 1160, 1223, 1383, 1465, 1740, 2956, 3019 cm^{-1}. HRMS: calcd. for $C_{12}H_{19}O_2$ [M + H]$^+$ 195.1385; found 195.1385.

6-[4-(4-Hydroxy-3-methoxyphenyl)but-2-enyl]-3,6-dihydropyran-2-one (17e): Eluent: hexanes/EtOAc, 80:20 then 50:50. Orange oil. Yield: 70% (239 mg, 0.87 mmol). ^{1}H NMR: δ = 2.46–2.51 (m, 2 H, CH_2-CH=), 2.99–3.01 (m, 2 H, CH_2-CO_2), 3.27 (d, J = 6.6 Hz, 2 H, CH_2-Ar), 3.87 (s, 3 H, O-CH_3), 4.99–5.02 (m, 1 H, CH-O), 5.47 (dt, J = 15.4, 6.9 Hz, 1 H, CH_2-CH=), 5.48 (s, 1 H, OH), 5.73 (dt, J = 15.4, 6.6 Hz, 1 H, CH=CH_2), 5.80 (br. s, 2 H, 2 CH=), 6.65 (m, 2 H_{ar}), 6.83 (dd, J = 7.1, 1.1 Hz, 1 H_{ar}) ppm. ^{13}C NMR: δ = 29.8 (CH_2-CO_2), 38.3 (CH_2), 38.5 (CH_2), 55.7 (CH_3), 79.0 (CH-O), 111.0 (CH), 114.2 (CH), 120.8 (CH), 121.7 (CH), 124.0 (CH), 125.7 (CH), 131.7 (C) 134.3 (CH), 143.8 (C), 146.5 (C), 169.0 (CO_2) ppm. IR: $\tilde{\nu}$ = 735, 972, 1034, 1122, 1151, 1233, 1268, 1382, 1430, 1514, 1601, 1735, 2936, 3413 cm^{-1}. HRMS: calcd. for $C_{16}H_{18}O_4$ [M]$^{+\cdot}$ 274.1205; found 274.1205.

Benzyl 5-(6-Oxo-5,6-dihydro-2*H*-pyran-2-yl)-pent-3-enoate (17f): Eluent: hexanes/EtOAc, 80:20. Colorless oil. Yield: 54% (140 mg, 0.49 mmol). ^{1}H NMR: δ = 2.49 (tt, J = 6.7, 1.1 Hz, 2 H, CH_2-

CH=), 3.01–3.02 (m, 2 H, CH_2-CO_2), 3.10 (dd, J = 6.7, 0.9 Hz, 2 H, CH_2-CO_2), 4.99–5.02 (m, 1 H, C*H*-O), 5.12 (s, 2 H, CH_2-O), 5.52–5.62 (m, 1 H, C*H*=), 5.67–5.77 (m, 1 H, C*H*=), 5.81 (br. s, 2 H, C*H*=C*H*) 7.35 (s, 5 H_{ar}) ppm. ^{13}C NMR: δ = 29.9 (*C*H_2-CO_2), 38.0 (CH_2), 38.5 (CH_2), 66.5 (O-CH_2), 78.9 (O-*CH*), 122.0 (*CH*), 125.6 (*CH*), 126.7 (*CH*), 127.6 (*CH*), 128.3 (3 *CH*), 128.6 (2 *CH*), 135.8 (*C*), 168.8 (CO_2), 171.3 (CO_2) ppm. IR: $\tilde{\nu}$ = 699, 736, 1163, 1731, 2943, 3054 cm^{-1}. HRMS: calcd. for $[M + H]^+$ 287.1283; found 287.1281.

General Procedure for Reconjugation: Pyran-2-one **17** (1 mmol) was first dissolved in THF (100 mL). After addition of DBU (0.1 mmol), the resulting mixture was stirred overnight until complete disappearance of the starting material (TLC control). The mixture was hydrolyzed with a saturated aqueous solution of ammonium chloride (15 mL). The solvent was removed by concentration, and the aqueous phase was extracted with dichloromethane. The organic layer was successively washed with water (10 mL) and brine (10 mL) and finally dried with $MgSO_4$. After filtration, the solution was concentrated under vacuum, and the crude mixture was purified by flash chromatography on silica.

6-Hept-2-enyl-5,6-dihydropyran-2-one (12a): Eluent: hexanes/EtOAc, 95:5. Colorless oil. Yield: 70% (50 mg, 0.26 mmol). ^{1}H NMR: δ = 0.88 (t, J = 7.1 Hz, 3 H, 3 H, CH_3), 1.31–1.33 (m, 4 H, CH_2-CH_2), 2.01 (br. q, J = 7.0 Hz, 2 H, =CH-CH_2), 2.30–2.36 (m, 2 H, CH_2-CH=), 2.39–2.53 (m, 2 H, CH_2), 4.43 (br. quint., J = 7.0 Hz, 1 H, C*H*-O), 5.39–5.46 (m, 1 H, C*H*=), 5.51–5.58 (m, 1 H, C*H*=), 6.01 (dt, J = 9.8, 1.8 Hz, 1 H, C*H*-CO_2), 6.87 (dt, J = 9.8, 4.3 Hz, 1 H, =C*H*) ppm. ^{13}C NMR: δ = 13.9 (*C*H_3), 22.2 (*C*H_2), 28.7 (*C*H_2), 31.5 (*C*H_2), 32.3 (*C*H_2), 38.0 (*C*H_2), 77.8 (*CH*-O), 121.6 (*CH*), 123.4 (*CH*), 135.2 (*CH*), 145.2 (*CH*), 164.5 (*C*O_2) ppm. IR: $\tilde{\nu}$ = 736, 816, 1042, 1251, 1387, 1721, 2918, 3011 cm^{-1}. HRMS: calcd. for $C_{12}H_{19}O_2$ $[M + H]^+$ 194.1307; found 194.1307.

6-Hex-2-enyl-5,6-dihydropyran-2-one (12b): Eluent: hexanes/EtOAc, 95:5. Colorless oil. Yield: 80% (64 mg, 0.36 mmol). ^{1}H NMR: δ = 0.88 (t, J = 7.2 Hz, 3 H, CH_3), 1.38 (sext., J = 7.3 Hz, 2 H, CH_2), 1.99 (br. q, J = 7.2 Hz, 2 H, CH_2), 2.31–2.37 (m, 2 H, CH_2-CH=), 2.39–2.52 (m, 2 H, CH_2-CH=), 4.39–4.48 (m, 1 H, C*H*-O), 5.42 (dt, J = 15.3, 6.6 Hz, 1 H, C*H*=), 5.56 (dt, J = 15.3, 6.6 Hz, 1 H, C*H*=), 6.02 (dt, J = 9.8, 1.8 Hz, 1 H, C*H*-CO_2), 6.87 (dt, J = 9.8, 4.2 Hz, 1 H, C*H*=) ppm. ^{13}C NMR: δ = 13.6 (*C*H_3), 22.4 (*C*H_2), 28.7 (*C*H_2), 34.7 (*C*H_2), 37.9 (*C*H_2), 77.7 (*CH*-O), 121.3 (*CH*), 123.6 (*CH*), 134.9 (*CH*), 145.2 (*CH*), 164.5 (CO_2) ppm. IR: $\tilde{\nu}$ = 735, 815, 1040, 1248, 1387, 1723, 2930, 3028 cm^{-1}. HRMS: calcd. for $C_{11}H_{16}O_2$ $[M]^{+\cdot}$ 180.1150; found 180.1151.

6-(Cinnamyl)-5,6-dihydropyran-2-one (12c): Eluent: hexanes/EtOAc, 80:20 then 50:50. Colorless oil. Yield: 67% (80 mg, 0.37 mmol). ^{1}H NMR: δ = 2.37–2.42 (m, 2 H, CH_2-CH=), 2.63–2.73 (m, 2 H, CH_2-CH=), 4.52–4.61 (m, 1 H, C*H*-O), 6.03 (dt, J = 9.6 and 1.7 Hz, 1 H, *CH*-CO_2), 6.24 (dt, J = 15.8 and 7.1 Hz, 1 H, CH_2-C*H*=), 6.50 (d, J = 15.8 Hz, 1 H, C*H*-Ph), 6.88 (dt, J = 9.6 and 3.7 Hz, 1 H, C*H*-CH_2), 7.22–7.30 (m, 5 H, H_{ar}) ppm. ^{13}C NMR: δ = 28.7 (*C*H_2), 38.2 (*C*H_2), 77.4 (*CH*-O), 121.3 (*CH*), 123.7 (*CH*), 126.2 (2 *CH*), 127.5 (*CH*), 128.5 (2 *CH*), 133.7 (*CH*), 136.9 (*C*), 145.1 (*CH*), 164.3 (*C*O_2) ppm. IR: $\tilde{\nu}$ = 694, 736, 817, 855, 967, 1043, 1147, 1250, 1387, 1494, 1598, 1719, 2911, 3027, 3057 cm^{-1}. HRMS: calcd. for $C_{14}H_{14}O_2$ $[M]^{+\cdot}$: 214.0994; found 214.0993.

6-(5-Methyl-hex-2-enyl)-5,6-dihydropyran-2-one (12d): Eluent: hexanes/EtOAc, 95:5 then 90:10. Colorless oil. Yield: 65% (66 mg, 0.34 mmol). ^{1}H NMR: δ = 0.87 (d, J = 6.6 Hz, 6 H, 2 *CH*$_3$), 1.58–1.65 [m, 1 H, C*H*(CH_3)$_2$], 1.90 (t, J = 7.1 Hz, 2 H, *CH*$_2$), 2.31–2.35 (m, 2 H, *CH*$_2$), 2.38–2.53 (m, 2 H, *CH*$_2$), 4.39–4.48 (m, 1 H, C*H*-O), 5.41 (dt, J = 15.2, 6.9 Hz, 1 H, C*H*=), 5.54 (dt, J = 15.2, 7.1 Hz, 1 H, C*H*=), 6.01 (dt, J = 9.8, 1.8 Hz, 1 H, C*H*-CO_2), 6.87 (dt, J = 9.8, 4.5 Hz, 1 H, C*H*=) ppm. ^{13}C NMR: δ = 22.2 (2 *CH*$_3$), 28.2 (*CH*), 28.6 (*CH*$_2$), 37.9 (*CH*$_2$), 41.9 (*CH*$_2$), 77.7 (*CH*-O), 121.2 (*CH*), 124.5 (*CH*), 133.8 (*CH*), 145.2 (*CH*), 164.4 (CO_2) ppm. IR: $\tilde{\nu}$ = 736, 814, 972, 1040, 1151, 1247, 1386, 1465, 1727, 2956, 3018 cm^{-1}. HRMS: calcd. for $C_{12}H_{19}O_2$ $[M + H]^+$ 195.1385; found 195.1385.

6-[4-(4-Hydroxy-3-methoxyphenyl)but-2-enyl]-5,6-dihydropyran-2-one (12e): Eluent: hexanes/EtOAc, 50:50. Orange oil. Yield: 52% (135 mg, 0.49 mmol). ^{1}H NMR: δ = 2.31–2.35 (m, 2 H, CH_2-CHO), 2.44–2.53 (m, 2 H, CH_2-CHO), 3.29 (d, J = 6.6 Hz, 2 H, CH_2-ar), 3.87 (s, 3 H, O-CH_3), 4.42–4.51 (m, 1 H, C*H*-O), 5.47 (s, 1 H, OH), 5.54 (dt, J = 15.0, 6.9 Hz, 1 H, CH_2-C*H*=), 5.69 (dt, J = 15.0, 6.6 Hz, 1 H, CH_2-C*H*=), 6.02 (dt, J = 9.6, 1.7 Hz, 1 H, C*H*-CO_2), 6.64–6.67 (m, 2 H, 1 C*H*= and 1 CH_{ar}), 6.82–6.90 (m, 2 H, 2 CH_{ar}) ppm. ^{13}C NMR: δ = 28.6 (*C*H_2), 37.6 (*C*H_2), 38.5 (*C*H_2), 55.7 (*CH*$_3$), 77.5 (*CH*-O), 111.1 (*CH*), 114.2 (*CH*), 120.8 (*CH*), 121.0 (*CH*), 124.7 (*CH*), 132.0 (*C*), 133.7 (*CH*), 143.8 (*C*), 145.2 (*CH*), 146.5 (C), 164.4 (*C*O_2) ppm. IR: $\tilde{\nu}$ = 733, 910, 1037, 1122, 1149, 1266, 1387, 1514, 1612, 1715, 2939, 3537 cm^{-1}. HRMS: calcd. for $C_{16}H_{18}O_4$ $[M]^{+\cdot}$ 274.1205; found 274.1209.

Benzyl 5-(6-Oxo-3,6-dihydro-2*H*-pyran-2-yl)pent-2-enoate (12f′): Eluent: hexanes/EtOAc, 80:20 then 50:50. Yield: 49% (68 mg, 0.23 mmol). Orange oil. ^{1}H NMR: δ = 1.74–1.84 (m, 1 H, O-CH-CH_2), 1.90–2.01 (m, 1 H, O-CH-CH_2), 2.28–2.36 (m, 2 H, CH_2-CH=), 2.40–2.53 (m, 2 H, CH_2-CH=), 4.38–4.47 (m, 1 H, C*H*-O), 5.17 (s, 2 H, O-CH_2), 5.92 (dt, J = 15.6, 1.5 Hz, 1 H, C*H*=), 6.03 (dt, J = 9.6, 1.8 Hz, 1 H, C*H*-CO_2), 6.87 (dt, J = 9.6, 4.5 Hz, 1 H, C*H*=), 6.99 (dt, J = 15.6, 6.9 Hz, 1 H, C*H*=), 7.36 (s, 5 H, H_{ar}) ppm. ^{13}C NMR: δ = 27.4 (*C*H_2), 29.4 (*C*H_2), 33.1 (*C*H_2), 66.2 (O-*C*H_2), 77.4 (*CH*-O), 121.4 (*CH*), 122.1 (*CH*), 128.2 (3 *CH*), 128.4 (2 *CH*), 136.0 (*C*), 144.9 (*CH*), 147.8 (*CH*), 164.1 (*C*O_2), 166.1 (*C*O_2) ppm. IR: $\tilde{\nu}$ = 735, 816, 1040, 1164, 1253, 1380, 1654, 1719, 2944, 3059 cm^{-1}. HRMS: calcd. for $[M + H]^+$ 287.1283; found 287.1282.

Synthesis of Rugulatone (3)

6-(4-Oxo-6-phenyl-hex-2-enyl)-3,6-dihydropyran-2-one (23): A solution of ester **15** (140 mg, 0.84 mmol) and 5-phenyl-pent-1-en-3-one (**14b**; 674 mg, 4.21 mmol) in dichloromethane (168 mL) was deoxygenated by bubbling an argon stream for 10 min. Grubbs type II catalyst **5** (36 mg, 0.04 mmol) was directly added, and the resulting solution was heated for 6 h. After cooling, an additional amount of **5** (18 mg, 0.02 mmol) was promptly added. The mixture was heated to reflux overnight. After cooling, the solvent was removed by concentration. Compound **23** (119 mg, 0.44 mmol) was isolated pure as a pale yellow oil after flash chromatography on silica (EtOAc/hexanes, 5:95 then 20:80). Yield: 57%. ^{1}H NMR: δ = 2.61–2.68 (m, 2 H, O-CH-CH_2), 2.83–2.95 (m, 4 H, CH_2-CH_2), 3.03–3.06 (m, 2 H, CH_2-CO_2), 5.08–5.12 (m, 1 H, C*H*-O), 5.78–5.83 (m, 1 H, C*H*=), 5.88–6.24 (m, 1 H, C*H*=), 6.22 (d, J = 15.8 Hz, 1 H, C*H*-CO), 6.76 (dt, J = 15.8, 7.3 Hz, 1 H, CH_2-CH), 7.17–7.28 (m, 5 H, H_{ar}) ppm. ^{13}C NMR: δ = 29.8 (*C*H_2), 29.9 (*C*H_2), 38.4 (*C*H_2-CH=), 42.1 (*C*H_2-CO), 77.9 (*CH*-O), 122.9 (*CH*), 125.2 (*CH*), 126.2 (*CH*), 128.4 (2 *CH*), 128.5 (2 *CH*), 133.7 (*CH*), 139.5 (*CH*), 141.1 (*C*), 168.9 (*C*O_2), 198.8 (*CO*) ppm. IR: $\tilde{\nu}$ = 700, 735, 976, 1073, 1157, 1225, 1377, 1454, 1496, 1633, 1673, 1740, 2926, 3027 cm^{-1}. HRMS: calcd. for $C_{17}H_{19}O_3$ $[M + H]^+$ 271.1334; found 271.1334.

6-(4-Hydroxy-6-phenylhex-2-enyl)-3,6-dihydropyran-2-one (25): A 1 M solution of (*R*)-1-methyl-3,3-diphenylhexahydropyrrolo[1,2c]-[1,3,2]-oxazaborole (**24**) in toluene (0.02 mL, 0.02 mmol) was poured, under an argon atmosphere, into a flask containing di-

chloromethane (1 mL). After cooling to 0 °C, a 1:1 complex borane–dimethylsulfide in dichloromethane (0.14 mL, 0.14 mmol) was added dropwise. After 30 min at this temperature, lactone **23** (63 mg, 0.23 mmol) dissolved in dichloromethane (1 mL) was rapidly added. After only 2 min, the reaction mixture was hydrolyzed with a saturated solution of ammonium chloride. The aqueous layer was extracted with dichloromethane (2 × 5 mL). The organic layer was successively washed with water and brine. After drying with $MgSO_4$ and filtration, the solvent was removed by concentration. The residue was purified by flash chromatography on silica (EtOAc/hexanes, 20:80) to deliver compound **25** (32 mg, 0.12 mmol) as a pale yellow oil. Yield: 52%. ^{1}H NMR: δ = 1.79–1.90 (m, 2 H, CHOH-CH_2), 2.50–2.51 (m, 2 H, CH_2-CH=), 2.65–2.75 (m, 2 H, CH_2-Ph), 3.03–3.05 (m, 2 H, CH_2-CO_2), 4.09–4.18 (m, 1 H, C*H*-OH), 5.02–5.03 (m, 1 H, C*H*-O), 5.65–5.68 (m, 1 H, C*H*=), 5.71–5.73 (m, 1 H, CH_2-CH=), 5.81–5.89 (m, 2 H, C*H*=C*H*), 7.18–7.34 (m, 5 H, H_{ar}) ppm. ^{13}C NMR: δ = 29.9 (*C*H_2), 31.6 (*C*H_2-Ph), 31.7 (*C*H_2), 38.6 (*C*H_2-CH_2-Ph), 71.6 (*C*H-OH), 78.9 (*C*H-O), 121.9 (*C*H), 124.1 (*C*H), 124.2 (*C*H), 125.6 (*C*H), 125.8 (2 *C*H), 128.3 (*C*H), 133.8 (*C*H), 137.9 (*C*H), 141.8 (*C*), 169.1 (*C*O_2) ppm. IR: $\tilde{\nu}$ = 701, 738, 1072, 1265, 1454, 1735, 2927, 3416 cm^{-1}. HRMS: calcd. for $C_{17}H_{20}O_3Na$ 295.1310; found 295.1310.

6-(4-Hydroxy-6-phenylhex-2-enyl)-5,6-dihydropyran-2-one (26): Lactone **25** (110 mg, 0.40 mmol) was dissolved in THF (2 mL). After addition of DBU (5 μL, 0.04 mmol, 0.1 equiv.), the reaction mixture was stirred at room temperature for 2 h. After addition of a solution of ammonium chloride (2 mL), the aqueous layer was extracted with dichloromethane (2 × 3 mL). The organic layer was washed with water (2 mL) then with brine (2 mL) and finally dried with $MgSO_4$. After filtration, the solvent was removed by concentration. The crude mixture isolated as a colorless oil was directly used in the next step. ^{1}H NMR: δ = 2.31–2.35 (m, 2 H, CHOH-CH_2), 2.46–2.52 (m, 2 H, *C*H_2-CH=), 2.67–2.74 (m, 2 H, CH_2-Ph), 3.72–3.76 (m, 2 H, CH_2-CH=), 4.09–4.13 (m, 1 H, C*H*-OH), 4.42–4.49 (m, 1 H, C*H*-O), 5.66–5.71 (m, 2 H, 2 C*H*=), 6.00–6.04 (m, 1 H, C*H*-CO_2), 6.84–6.88 (m, 1 H, C*H*=), 7.18–7.31 (m, 5 H, H_{ar}) ppm. ^{13}C NMR: δ = 28.7 (*C*H_2), 31.7 (*C*H_2-Ph), 37.4 (*C*H_2), 38.7 (*C*H_2-CH_2-Ph), 71.6 (*C*H-OH), 77.2 (*C*H-O), 121.2 (C*H*-CO_2), 124.8 (*C*H), 124.9 (*C*H), 125.8 (*C*H), 128.3 (2 *C*H), 133.8 (*C*H), 137.2 (*C*H), 141.9 (*C*), 145.2 (C*H*=), 164.4 (*C*O_2) ppm.

Rugulactone (3): To a solution of compound **26** (110 mg, 0.40 mmol) in dichloromethane (2 mL) was added at 0 °C a solution of Dess–Martin periodinane in the same solvent (1.04 mL, 0.49 mmol). After stirring for 15 min the reaction was allowed to reach room temperature and was stirred for an additional hour. The mixture was hydrolyzed with a saturated aqueous solution of ammonium chloride (2 mL) followed by a saturated aqueous solution of $Na_2S_2O_3$. After extraction with dichloromethane, the organic layers were successively washed with water and brine. After drying over $MgSO_4$ and filtration, the solvent was removed by concentration. The crude product was purified by flash chromatography on silica (EtOAc/hexanes, 50:50). Rugulactone (**3**; 60 mg, 0.22 mmol) was isolated as a colorless oil. Yield: 55% over 2 steps. ^{1}H NMR: δ = 2.30–2.35 (m, 2 H, CH_2-CO), 2.60–2.67 (m, 2 H, CH_2-Ph), 2.87–2.96 (m, 4 H, 2 CH_2), 4.54 (br. quint., J = 6.9 Hz, 1 H, C*H*-O), 6.04 (dt, J = 9.8, 1.8 Hz, 1 H, C*H*-CO_2), 6.19 (dt, J = 15.8, 1.3 Hz, 1 H, C*H*-CO), 6.79 (dt, J = 15.8, 7.1 Hz, 1 H, =C*H*), 6.87 (dt, J = 9.8, 4.3 Hz, 1 H, =C*H*), 7.16–7.35 (m, 5 H, H_{ar}) ppm. ^{13}C NMR: δ = 28.9 (*C*H_2), 30.0 (*C*H_2-Ph), 37.5 (*C*H_2), 41.7 (*C*H_2-CO), 76.1 (*C*H-O), 121.4 (*C*H-CO_2), 126.1 (*C*H), 128.4 (2 *C*H), 128.5 (*C*H), 133.5 (*C*H), 140.1 (*C*H), 141.2 (*C*H), 144.8 (*C*H), 163.8 (*C*O_2), 199.0 (*C*O) ppm. IR: $\tilde{\nu}$ = 703, 738, 896, 1046, 1265, 1422, 1724, 3055 cm^{-1}. HRMS: calcd. for $[C_{17}H_{18}O_3 + H]^+$ 271.1334; found 271.1333.

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