Total synthesis of capsanthin and capsorubin using Lewis acid-promoted regio- and stereoselective rearrangement of tetrasubstituted epoxides.

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Synthesis and characterization data of compounds 7d-f, 8d,f, 9d,e, 11, 14-17 and 5
Spectral data of compounds 1 and 2
**Ethyl (2E,4E)-3-Methyl-5-(2,2,6-trimethyl-7-oxobicyclo[4.1.0]hept-1-yl)penta-2,4-dienoate 7d**

A solution of the triethyl phosphonoacetate in dry THF (15 ml) was added dropwise to a stirred suspension of NaH (60% oil dispersion; 880 mg, 22 mmol) in dry THF (20 ml) at 0 °C. After being stirred at 0 °C for 15 min, a solution of the β-ionone 10 (2.50 g, 13 mmol) in dry THF (15 ml) was added to it. The reaction mixture was then warmed to 50 °C and stirring was continued for 3 h. The reaction was quenched by addition of saturated aq. NH₄Cl and the mixture was extracted with ether. The extracts were washed with brine, dried and evaporated to give a residue, which was purified by CC (ether-hexane, 7:93) to afford the corresponding conjugated ester as an isomeric mixture (2.40 g, 70%; all-E:9Z, ~8:1). To an ice-cooled solution of this ester in CH₂Cl₂ (20 ml) was added a solution of MCPBA (70%; 2.71 g, 17.8 mmol) in CH₂Cl₂ (15 ml) and the mixture was stirred at rt for 2 h. After addition of 1% aq. Na₂S₂O₃, CH₂Cl₂ was evaporated and the resulting mixture was extracted with ether. The extracts were washed with saturated aq. NaHCO₃ and brine. Evaporation of the dried solvent gave a residue, which was purified by CC (ether-hexane, 1:9) to give the epoxy dienoate 7d (1.72 g, 48% from 10) and its 9Z-isomer (230 mg, 6% from 10) as colorless oils, respectively.

**Compound 7d:** \(\lambda_{\text{max}}(\text{EtOH})/\text{nm} 265\); \(\nu_{\text{max}}/\text{cm}^{-1} 1703\) (conj. OCO), 1634 and 1613 (C=C); \(\delta_H(300 \text{ MHz})\) 0.92 and 1.11 and 1.13 (each 3H, s, \text{gem-Me and 5-Me}), 1.28 (3H, t, \(J_{7, 1}\), \(CH₂CH₃\)), 1.08 (1H, m), 1.37–1.52 (3H, m) and 1.70–1.96 (2H, m) (2-H₂, 3-H₂ and 4-H₂), 2.29 (3H, d, \(J_{1, 9}\), Me), 4.17 (2H, q, \(J_{7, CH₂CH₃}\)), 5.79 (1H, q-like, \(J_{1, 10}\), 6.26 and 6.32 (each 1H, d, \(J_{16, 7-H}\) and 8-H)); \(m/z\) (EI) 278.1905 (M⁺, \(C_{17}H_{26}O₃\) requires 278.1880).

**9Z-Isomer of compound 7d:** \(\lambda_{\text{max}}(\text{EtOH})/\text{nm} 266\); \(\nu_{\text{max}}/\text{cm}^{-1} 1703\) (conj. OCO), 1636 and 1604 (C=C); \(\delta_H(300 \text{ MHz})\) 0.97, 1.10 and 1.18 (each 3H, s, \text{gem-Me and 5-Me}), 1.28 (3H, t, \(J_{7, 1}\), \(CH₂CH₃\)), 1.07 (1H, m), 1.37–1.55 (3H, m) and 1.70–1.96 (2H, m) (2-H₂, 3-H₂ and 4-H₂), 2.00 (3H, d, \(J_{1, 9}\), Me), 4.17 (2H, q, \(J_{7, CH₂CH₃}\)), 5.69 (1H, br s, 10-H), 6.24 (1H, d, \(J_{16, 7-H}\), 7.59 (1H, d, \(J_{16, 8-H}\)); \(m/z\) (EI) 278.1898 (M⁺, \(C_{17}H_{26}O₃\) requires 278.1880).

**Ethyl (2E,4E)-3-Methyl-5-(2,2,6-trimethyl-7-oxobicyclo[4.1.0]hept-1-yl)penta-2,4-dienal 7e**

A solution of the ester 7d (1.11 g, 4.0 mmol) in dry ether (20 ml) was added dropwise to a stirred suspension of LiAlH₄ (152 mg, 4.0 mmol) in dry ether at 0 °C. After being stirred at 0 °C for 15 min, the excess of
LiAlH₄ was decomposed by dropwise addition of water and the mixture was extracted with ether. The extracts were dried and evaporated to give a residue, which without purification was dissolved in ether-hexane (~1:4) and shaken with MnO₂ (5 g) at rt for 5 h. The mixture was filtered through Celite. Evaporation of the filtrate followed by purification by SCC (ether-hexane, 3:7) to provide the epoxy dienal 7e (898 mg, 96%) as a pale yellow oil; λ_max(EtOH)/nm 284; ν_max/cm⁻¹ 1662 (conj. CHO), 1629 and 1598 (C=C); δ_H(300 MHz) 0.94, 1.13 and 1.15 (each 3H, s, gem-Me and 5-Me), 1.08 (1H, m), 1.38–1.53 (3H, m) and 1.72–1.98 (2H, m) (2-H₂, 3-H₂ and 4-H₂), 2.28 (3H, d, J 1, 9-Me), 5.98 (1H, br d, J 8, 10-H), 6.38 and 6.49 (each 1H, d, J 16, 7-H and 8-H), 10.13 (1H, d, J 8, CHO); m/z (El) 234.1637 (M+, C₁₅H₂₂O₂ requires 234.1619).

Ethyl (2E,4E,6E)-5-Methyl-7-(2,2,6-trimethyl-7-oxobicyclo[4.1.0]hept-1-yl)hepta-2,4,6-trienoate 11

To a solution of triethyl phosphonoacetate (935 mg, 4.2 mmol) in dry THF (7 ml) was added BuLi (1.6 M in hexane; 2.71 ml, 4.3 mmol) at 0 °C. After being stirred at 0 °C for 15 min, a solution of the epoxy dienal 7e (650 mg, 2.8 mmol) in dry THF (5 ml) was added to the reaction mixture at 0 °C and stirring was continued for 15 min. After being quenched with saturated aq. NH₄Cl, the mixture was extracted with ether. The extracts were washed with brine, dried and evaporated to give the residue, which was purified by SCC (ether-hexane, 1:9) to provide the epoxy trienoate 11 (701 mg, 83%) as a pale yellow oil; λ_max(EtOH)/nm 311; ν_max/cm⁻¹ 1698 (conj. OCO), 1634 and 1610 (C=C); δ_H(300 MHz) 0.93, 1.11 and 1.14 (each 3H, s, gem-Me and 5-Me), 1.30 (3H, t, J 7, CH₂CH₃), 1.07 (1H, m), 1.37–1.52 (3H, m) and 1.67–1.96 (2H, m) (2-H₂, 3-H₂ and 4-H₂), 2.01 (3H, br s, 9-Me), 4.21 (2H, q, J 7, CH₂CH₃), 5.90 (1H, d, J 15.5, 12-H), 6.11 and 6.32 (each 1H, d, J 15.5, 7-H and 8-H), 6.19 (1H, br d, J 11.5, 10-H), 7.67 (1H, dd, J 15.5 and 11.5, 11-H); m/z (El) 304.2020 (M⁺, C₁₉H₂₈O₃ requires 304.2037).

(2E,4E,6E)-5-Methyl-7-(2,2,6-trimethyl-7-oxobicyclo[4.1.0]hept-1-yl)hepta-2,4,6-trienal 7f

Following the procedure described for the preparation of the epoxy dienal 7e, reduction of the epoxy trienoate 11 (852 mg) with LiAlH₄ followed by oxidation with MnO₂ provided the epoxy trienal 7f (650 mg, 89%) as a yellow oil; λ_max(EtOH)/nm 326; ν_max/cm⁻¹ 1673 (conj. CHO), 1602 (C=C); δ_H(300 MHz) 0.94, 1.12 and 1.15 (each 3H, s, gem-Me and 5-Me), 1.08 (1H, m), 1.38–1.53 (3H, m) and 1.70–1.97 (2H, m) (2-H₂, 3-H₂ and 4-H₂), 2.06 (3H, d, J 1, 9-Me), 6.19 (1H, dd, J 15.5 and 8, 12-H), 6.22 and 6.38 (each 1H, d, J
15.5, 7-H and 8-H), 6.33 (1H, br d, J 11.5, 10-H), 7.50 (1H, dd, J 15.5 and 11.5, 11-H), 9.62 (1H, d, J 8, CHO); m/z (EI) 260.1776 (M+, C\textsubscript{17}H\textsubscript{24}O\textsubscript{2} requires 260.1775).

**Treatment of the epoxy dienoate 7d with SnCl\textsubscript{4}**

To a solution of the epoxy dienoate 7d (150 mg, 0.54 mmol) in dry CH\textsubscript{2}Cl\textsubscript{2} (5 ml) was added SnCl\textsubscript{4} (1M in CH\textsubscript{2}Cl\textsubscript{2}; 1.2 ml, 1.2 mmol) at 0 °C. The mixture was stirred at 0 °C for 20 min and then poured into saturated aq. NaHCO\textsubscript{3} and extracted with ether. The extracts were washed with brine and dried. Evaporation of the solvent gave a residue, which was purified by SCC (ether-hexane, 1:9) to afford the 5,8-epoxide 8d (129 mg, 86%; 5,8-\textit{trans}:5,8-\textit{cis}, ~8:1) and the cyclopentyl ketone 9d (8 mg, 5%). A part of the diastereomeric mixture of 8d was separated by PHPLC [LiChrosorb Si 60 (7 μm) 2 × 25 cm; ether-hexane, 12:88] to provide each pure isomer, as a colorless oil, respectively.

**5,8-\textit{Trans}-isomer of 8d:** $\lambda_{\text{max}}$(EtOH)/nm 215; $\nu_{\text{max}}$/cm$^{-1}$ 1708 (conj. OCO), 1656 (C=C); $\delta_{\text{H}}$(300 MHz) 1.10 and 1.14 (each 3H, s, gem-Me), 1.27 (3H, t, J 7, CH\textsubscript{2}CH\textsubscript{3}), 1.44 (3H, s, 5-Me), 1.20 (1H, m), 1.46–1.69 (4H, m) and 1.98 (1H, m) (2-H\textsubscript{2}, 3-H\textsubscript{2} and 4-H\textsubscript{2}), 2.10 (3H, d, J 1, 9-Me), 4.16 (2H, q, J 7, CH\textsubscript{2}CH\textsubscript{3}), 5.12 (1H, br s, 8-H), 5.22 (1H, br s, 7-H), 5.96 (1H, quint-like, J 1, 10-H); m/z (EI) 278.1877 (M\textsuperscript{+}, C\textsubscript{17}H\textsubscript{26}O\textsubscript{3} requires 278.1880).

**5,8-\textit{Cis}-isomer of 8d:** $\lambda_{\text{max}}$(EtOH)/nm 216; $\nu_{\text{max}}$/cm$^{-1}$ 1709 (conj. OCO), 1656 (C=C); $\delta_{\text{H}}$(300 MHz) 1.09 and 1.17 (each 3H, s, gem-Me), 1.28 (3H, t, J 7, CH\textsubscript{2}CH\textsubscript{3}), 1.47 (3H, s, 5-Me), 1.20 (1H, m), 1.44–1.77 (4H, m) and 1.95 (1H, m) (2-H\textsubscript{2}, 3-H\textsubscript{2} and 4-H\textsubscript{2}), 2.12 (3H, s, 9-Me), 4.16 (2H, q, J 7, CH\textsubscript{2}CH\textsubscript{3}), 5.04 (1H, br s, 8-H), 5.31 (1H, d, J 2, 7-H), 5.99 (1H, quint-like, J 1, 10-H); m/z (EI) 278.1877 (M\textsuperscript{+}, C\textsubscript{17}H\textsubscript{26}O\textsubscript{3} requires 278.1880).

**Compound 9d:** $\lambda_{\text{max}}$(EtOH)/nm 279; $\nu_{\text{max}}$/cm$^{-1}$ 1709 (conj. OCO), 1676 (conj. CO), 1616 and 1594 (C=C); $\delta_{\text{H}}$(300 MHz) 0.85, 1.10 and 1.19 (each 3H, s, gem-Me and 5-Me), 1.30 (3H, t, J 7, CH\textsubscript{2}CH\textsubscript{3}), 1.45–1.78 (5H, m) and 2.48 (1H, m) (2-H\textsubscript{2}, 3-H\textsubscript{2} and 4-H\textsubscript{2}), 2.30 (3H, d, J 1, 9-Me), 4.20 (2H, q, J 7, CH\textsubscript{2}CH\textsubscript{3}), 6.07 (1H, br s, 10-H), 6.79 (1H, d, J 15.5, 7-H), 7.18 (1H, d, J 15.5, 8-H); m/z (EI) 278.1880 (M\textsuperscript{+}, C\textsubscript{17}H\textsubscript{26}O\textsubscript{3} requires 278.1880).

**Treatment of the epoxy dienoate 7d with tris(4-bromophenyl)aminium hexachloroantimonate**
To a solution of the epoxy dienoate 7d (150 mg, 0.54 mmol) in dry dry CH₂Cl₂ (5 ml) was added tris(4-bromophenyl)aminium hexachloroantimonate (44 mg, 0.054 mmol) at rt. The mixture was stirred at rt for 15 min and concentrated to give a residue, which was purified by SCC (ether-hexane, 1:9) to afford the 5,8-epoxide 8d (113 mg, 75%; 5,8-trans:5,8-cis, ~8:1) and the cyclopentyl ketone 9d (2 mg, 1%).

**Treatment of the epoxy dienal 7e with SnCl₄**

In the same manner as described for SnCl₄-treatment of the epoxy dienoate 7d, the epoxy dienal 7e (150 mg) was treated with SnCl₄ to give crude products, which were purified by SCC (ether-hexane, 3:7) to afford the cyclopentyl ketone 9e (137 mg, 91%) as a pale yellow oil; *λ*<sub>max</sub>(EtOH)/nm 287; *ν*<sub>max</sub>/cm<sup>−1</sup> 1667 (conj. CO + conj. CHO), 1589 (C=O); *δ*<sub>δ</sub>(300 MHz) 0.86, 1.11 and 1.20 (each 3H, s, gem-Me and 5-Me), 1.47–1.81 (5H, m) and 2.48 (1H, m) (2-H₂, 3-H₂ and 4-H₂), 2.32 (3H, d, *J* 1, 9-Me), 6.21 (1H, br d, *J* 8, 10-H), 6.90 (1H, d, *J* 15.5, 7-H), 7.25 (1H, d, *J* 15.5, 8-H), 10.18 (1H, d, *J* 8, CHO); *δ*<sub>δ</sub>(75 MHz) 13.28 (9-CH₃), 19.64, 34.36 and 40.41 (C₂, C₃ and C₄), 20.49, 24.56 and 25.50 (gem-CH₃ and 5-CH₃), 44.20 (C₁), 59.21 (C₅), 128.72 (C₇), 134.18 (C₁₀), 143.47 (C₈), 151.47 (C₉), 191.11 (C₁₁), 203.30 (C₆); *m/z* (EI) 234.1616 (M⁺, C₁₅H₂₂O₂ requires 234.1618).

**Treatment of the epoxy dienal 7f with SnCl₄**

In the same manner as described for SnCl₄-treatment of the epoxy dienoate 7d, the epoxy trienal 7f (307 mg) was treated with SnCl₄. Purification of the crude products by SCC (ether-hexane, 2:3) afforded the 5,8-epoxide 8f (211 mg, 69%; 5,8-trans:5,8-cis, 5:1), a part of which was separated by PHPLC [LiChrosorb Si 60 (7 µm) 2 × 25 cm; THF-hexane, 8:92] to provide each pure isomer as a pale yellow oil, respectively.

**5,8-Trans-isomer of 8f:** *λ*<sub>max</sub>(EtOH)/nm 284; *ν*<sub>max</sub>/cm<sup>−1</sup> 1678 (conj. CHO), 1633 and 1596 (C=C); *δ*<sub>δ</sub>(300 MHz) 1.12 and 1.16 (each 3H, s, gem-Me), 1.45 (3H, s, 5-Me), 1.22 (1H, m), 1.50–1.70 (4H, m) and 2.00 (1H, m) (2-H₂, 3-H₂ and 4-H₂), 1.89 (3H, d, *J* 1, 9-Me), 5.21 (2H, br s, 7-H and 8-H), 6.16 (1H, dd, *J* 15 and 8, 12-H), 6.41 (1H, br d, *J* 11.5, 10-H), 7.42 (1H, dd, *J* 15 and 11.5, 11-H), 9.60 (1H, d, *J* 8, CHO); *m/z* (EI) 260.1789 (M⁺, C₁₃H₂₄O₂ requires 260.1775).

**5,8-Cis-isomer of 8f:** *λ*<sub>max</sub>(EtOH)/nm 285; *ν*<sub>max</sub>/cm<sup>−1</sup> 1678 (conj. CHO), 1633 and 1595 (C=C); *δ*<sub>δ</sub>(300 MHz) 1.10 and 1.19 (each 3H, s, gem-Me), 1.47 (3H, s, 5-Me), 1.22 (1H, m), 1.48–1.72 (4H, m) and 1.96
(1H, m) (2-H<sub>2</sub>, 3-H<sub>2</sub> and 4-H<sub>2</sub>), 1.93 (3H, d, J 1, 9-Me), 5.11 (1H, br s, 8-H), 5.28 (1H, d, J 2, 7-H), 6.16 (1H, dd, J 15 and 8, 12-H), 6.43 (1H, br d, J 11.5, 10-H), 7.42 (1H, dd, J 15 and 11.5, 11-H), 9.60 (1H, d, J 8, CHO); m/z (EI) 260.1761 (M+, C<sub>17</sub>H<sub>24</sub>O<sub>2</sub> requires 260.1775).

**(1R)-3,5,5-Trimethyl-4-[(1E)-2-(tributylstannyl)ethenyl]cyclohex-3-enol 14**

To a mixture of the alkyne 13 (1.50 g, 9.15 mmol) and tributyltin hydride (3.70 ml, 13.7 mmol) was added AIBN (50 mg, 0.3 mmol) and the mixture was heated at 130 °C for 20 min. After cooling, the mixture was purified by low-pressure CC (acetone-hexane, 15:85) to give the vinylstannane 14 (3.68 g, 88%) as a colorless oil; [α]_<sub>D</sub><sup>25</sup> –69.9 (c 1.03, MeOH); ν<sub>max</sub>/cm<sup>−1</sup> 3606 and 3445 (OH), 1579 (C=C); δ<sub>H</sub>(300 MHz) 0.85–1.58 (27H, m, Bu<sub>x</sub>3), 1.04 and 1.05 (each 3H, s, gem-Me), 1.43 (1H, t, J 12, 2-H<sub>ax</sub>), 1.69 (3H, s, 5-Me), 1.75 (1H, ddd, J 12, 3.5 and 2, 2-H<sub:eq</sub>), 2.00 (1H, br dd, J 16.5 and 8.5, 4-H<sub>ax</sub>), 2.34 (1H, br dd, J 16.5 and 5.5, 4-H<sub:eq</sub>), 3.98 (1H, m, 3-H), 5.89 (1H, d, J 20, J'<sub>H</sub>H<sup>−117</sub>Sn<sup>−119</sub>Sn<sup>−84</sup>, 8-H), 6.31 (1H, br d, J 20, J'<sub>H</sub>H<sup>−117</sub>Sn<sup>−119</sub>Sn<sup>−65</sup>, 7-H).

**Ethyl (2E,4E)-5-[(4R)-4-Hydroxy-2,6,6-trimethylcyclohex-1-enyl]-3-methylpenta-2,4-dienoate 15**

A suspension of the vinylstannane 14 (1.12 g, 2.46 mmol), the vinyltriflate 23 (970 mg, 3.70 mmol), AsPh<sub>3</sub> (150 mg, 0.49 mmol) and Pd<sub>2</sub>dba<sub>2</sub>•CHCl<sub>3</sub> (64 mg, 0.062 mmol) in DMF (5 ml) was stirred at 50 °C for 4 h. The mixture was diluted with ether and washed with brine. Evaporation of the dried solution gave a residue, which was purified by SCC (acetone-hexane, 15:85) to afford the dienoate 15 (629 mg, 92%) as a pale yellow oil; [α]<sub>D</sub><sup>26</sup> –94.5 (c 1.10, MeOH); λ<sub>max</sub>/(EtOH)/nm 259 and 296; ν<sub>max</sub>/cm<sup>−1</sup> 3607 and 3461 (OH), 1702 (conj. OCO), 1607 (C=C); δ<sub>H</sub>(300 MHz) 1.06 and 1.07 (each 3H, s, gem-Me), 1.29 (3H, t, J 7, CH<sub>3</sub>CH<sub>3</sub>), 1.48 (1H, t, J 12, 2-H<sub>ax</sub>), 1.71 (3H, s, 5-Me), 1.78 (1H, ddd, J 12, 4 and 2, 2-H<sub:eq</sub>), 2.05 (1H, br dd, J 17 and 9, 4-H<sub>ax</sub>), 2.33 (3H, d, J 1, 9-Me), 2.39 (1H, br dd, J 17 and 5.5, 4-H<sub:eq</sub>), 4.00 (1H, m, 3-H), 4.18 (2H, q, J 7, CH<sub>2</sub>CH<sub>3</sub>), 5.75 (1H, br s, 10-H), 6.09 (1H, d, J 16, 8-H), 6.50 (1H, d, J 16, 7-H); m/z (EI) 278.1891 (M<sup>+</sup>, C<sub>17</sub>H<sub>26</sub>O<sub>3</sub> requires 278.1881).

**Ethyl (2E,4E)-5-[(4R)-4-tert-Butyldimethylsilyloxy-2,6,6-trimethylcyclohex-1-enyl]-3-methylpenta-2,4-dienoate 16**
A solution of TBSCl (1.17 g, 7.76 mmol) in dry CH2Cl2 (5 ml) was added slowly to a stirred solution of the hydroxy compound 15 (1.44 g, 5.18 mmol), 4-dimethylaminopyridine (DMAP) (760 mg, 6.2 mmol) and Et3N (0.87 ml, 6.2 mmol) in dry CH2Cl2 (10 ml) at 0 °C. The mixture was stirred at rt for 1 h, poured into chilled water and extracted with ether. The extracts were washed successively with aq. 3% HCl, saturated aq. NaHCO3 and brine. Evaporation of the dried solution gave a residue, which was purified by SCC (ether-hexane, 5:95) to afford the TBS ether 16 (1.86 g, 92%) as a pale yellow oil; $\left[\alpha\right]_D^{26} -80.2$ (c 1.03, MeOH); $\lambda_{\text{max}}$(EtOH)/nm 258 and 296; $\nu_{\text{max}}$/cm$^{-1}$ 1703 (conj. OCO), 1607 (C=C); $\delta_H$(300 MHz) 0.08 (6H, s, SiMe×2), 0.91 (9H, s, tert-Bu), 1.04 and 1.06 (each 3H, s, gem-Me), 1.29 (3H, t, $J_7$ CH$_2$CH$_3$), 1.50 (1H, t, $J_{12}$, 2-H$_{ax}$), 1.67 (1H, ddd, $J_{12}$, 3.5 and 2, 2-H$_{eq}$), 1.70 (3H, s, 5-Me), 2.07 (1H, br dd, $J_{17.5}$ and 9.5, 4-H$_{ax}$), 2.05 (1H, br dd, $J_{17.5}$ and 6, 4-H$_{eq}$), 2.33 (3H, d, $J_{1}$, 9-Me), 3.95 (1H, m, 3-H), 4.18 (2H, q, $J_7$, CH$_2$CH$_3$), 5.74 (1H, br s, 10-H), 6.09 (1H, d, $J_{16}$, 8-H), 6.50 (1H, d, $J_{16}$, 7-H); m/z (EI) 392.2743 (M$, C_{23}H_{40}O_3$Si requires 392.2744).

Epoxidation of the ester 16

A solution of MCPBA (80%, 2.48 g, 11.5 mmol) in CH$_2$Cl$_2$ (30 ml) was added dropwise to an ice-cooled solution of the ester 16 (4.09 g, 10.4 mmol) in CH$_2$Cl$_2$ (30 ml) and the mixture was stirred at 0 °C for 1 h. After the reaction mixture was quenched with aq. 10% Na$_2$S$_2$O$_3$, CH$_2$Cl$_2$ was evaporated off and the organics were extracted with ether. The extracts were washed with saturated aq. NaHCO$_3$ and brine. Evaporation of the dried extracts gave a residue, which was purified by CC (ether-hexane, 98.5:1.5) to afford the anti-epoxide 17a (1.18 g, 28%) and the syn-epoxide 17b (2.77 g, 65%) as colorless oils.

**Compound 17a:** $[\alpha]_D^{21} -58.4$ (c 1.06, MeOH); $\lambda_{\text{max}}$(EtOH)/nm 264; $\nu_{\text{max}}$/cm$^{-1}$ 1704 (conj. OCO), 1634 and 1613 (C=C); $\delta_H$(300 MHz) 0.05 (6H, s, SiMe×2), 0.88 (9H, s, tert-Bu), 0.95, 1.14 and 1.15 (each 3H, s, gem-Me and 5-Me), 1.26 (1H, dd, $J_{13}$ and 10, 2-H$_{ax}$), 1.28 (3H, t, $J_{7}$, CH$_2$CH$_3$), 1.51 (1H, ddd, $J_{13}$, 3.5 and 1.5, 2-H$_{eq}$), 1.65 (1H, dd, $J_{14}$ and 8, 4-H$_{ax}$), 2.25 (1H, ddd, $J_{14}$, 5 and 1.5, 4-H$_{eq}$), 2.29 (3H, d, $J_{1}$, 9-Me), 3.85 (1H, m, 3-H), 4.17 (2H, q, $J_{7}$, CH$_2$CH$_3$), 5.79 (1H, br s, 10-H), 6.25 and 6.33 (each 1H, d, $J_{15.5}$, 7-H and 8-H); m/z (EI) 408.2711 (M$, C_{23}H_{40}O_4$Si requires 408.2693).

**Compound 17b:** $[\alpha]_D^{23} +5.7$ (c 1.05, MeOH); $\lambda_{\text{max}}$(EtOH)/nm 264; $\nu_{\text{max}}$/cm$^{-1}$ 1703 (conj. OCO), 1634 and 1613 (C=C); $\delta_H$(300 MHz) 0.05 (6H, s, SiMe×2), 0.88 (9H, s, tert-Bu), 0.95, 1.14 and 1.17 (each 3H, s,
Preparation of the epoxy dienoate 17a from the epoxy aldehyde 18

To a solution of the phosphonate 24 (1.33 g, 5.03 mmol) in dry THF (10 ml) was added n-BuLi (1.58 M in hexane; 3.2 ml, 5.06 mmol) at 0 °C and the mixture was stirred for a further 15 min. A solution of the aldehyde 18\(^{21}\) (1.00 g, 3.36 mmol) was added to this mixture and the mixture was stirred at 0 °C for 20 min. After being quenched with saturated aq. NH\(_4\)Cl, the mixture was extracted with ether. The extracts were washed with brine, dried and evaporated to give the residue, which was purified by CC (ether-hexane, 15:85) to provide the epoxy dienoate 17a (920 mg, 67%) and its 9\(^Z\)-isomer (351 mg, 26%) as pale yellow oils.

9\(^Z\)-Isomer of 17a: \([\alpha]_D^{22} –21.4\) (c 0.94, MeOH); \(\lambda_{\text{max}}\) (EtOH)/nm 265; \(\nu_{\text{max}}/\text{cm}^{-1}\) 1703 (conj. OCO), 1636 and 1604 (C=C); \(\delta_n\) (300 MHz) 0.04 (6H, s, SiMe\(_2\)), 0.87 (9H, s, tert-Bu), 0.98, 1.12 and 1.18 (each 3H, s, gem-Me and 5-Me), 1.24 (1H, dd, J 13 and 10, 2-H\(_{ax}\)), 1.27 (3H, t, J 7, CH\(_2\)CH\(_3\)), 1.51 (1H, ddd, J 13, 3.5 and 1.5, 2-Heq), 1.64 (1H, dd, J 14 and 8, 4-H\(_{ax}\)), 1.99 (3H, d, J 1, 9-Me), 2.24 (1H, ddd, J 14, 5 and 1.5, 4-H\(_{eq}\)), 3.86 (1H, m, 3-H), 4.15 (2H, q, J 7, CH\(_2\)CH\(_3\)), 5.68 (1H, br s, 10-H), 6.25 (1H, dd, J 16 and 0.5, 7-H), 7.58 (1H, dd, J 16 and 0.5, 8-H); \(m/z\) (EI) 408.2696 (M\(^+\), C\(_{23}\)H\(_{40}\)O\(_4\)Si requires 408.2693).

(2\(E\),4\(E\))-3-Methyl-5-\((1S,4S,6R)-4\text{-}\text{tert\text{-}butyldimethylsilyloxy\text{-}2,2,6\text{-}trimethyl\text{-}7\text{-}oxabicyclo\[4.1.0\]hept-1\text{-}yl\})\text{penta\text{-}2,4-dienal}\ 5

Following the procedure described for the preparation of the epoxy dienal 7e, reduction of the epoxy dienoate 15a (690 mg) with LiAlH\(_4\) followed by oxidation with MnO\(_2\) provided the crude products, which were purified by SCC (acetone-hexane, 1:4) to give the epoxy dienal 5 (604 nmg, 98%) as a pale yellow oil; \([\alpha]_D^{21} –65.8\) (c 1.09, MeOH); \(\lambda_{\text{max}}\) (EtOH)/nm 282; \(\nu_{\text{max}}/\text{cm}^{-1}\) 1662 (conj. CHO), 1630 and 1598 (C=C); \(\delta_n\) (300 MHz) 0.05 and 0.06 (each 3H, s, SiMe\(_2\)), 0.88 (9H, s, tert-Bu), 0.96 (3H, s) and 1.17 (6H, s) (gem-Me and 5-Me), 1.27 (1H, dd, J 13 and 10, 2-H\(_{ax}\)), 1.52 (1H, ddd, J 13, 3.5 and 1.5, 2-H\(_{eq}\)), 1.67 (1H,
dd, J 14.5 and 8, 4-Hax), 2.26 (1H, ddd, J 14.5, 5 and 1.5, 4-Heq), 2.28 (3H, d, J 1, 9-Me), 3.86 (1H, m, 3-H), 5.97 (1H, br d, J 8, 10-H), 6.37 and 6.50 (each 1H, d, J 15.5, 7-H and 8-H), 10.13 (1H, s, J 8, CHO); m/z (EI) 364.2439 (M+, C_{21}H_{36}O_{3}Si requires 364.2432).

Preparation of the Wittig salt 20

A solution of the ester 15 (1.00 g, 3.6 mmol) in dry ether (40 ml) were added dropwise to a stirred suspension of LiAlH_{4} (165 mg, 4.3 mmol) in dry ether at 0 °C. After being stirred at 0 °C for 15 min, the excess of LiAlH_{4} was decomposed by dropwise addition of water and the mixture was extracted with ether. The extracts were dried and evaporated to give a residue, which was purified by SCC (acetone-hexane, 3:7) to afford the corresponding alcohol (723 mg, 85%). A solution of this alcohol (3.1 mml) and triphenylphosphine hydrobromide (1.05 g, 3.1 mml) in MeOH (20 ml) was stirred at rt for 48 h. Evaporation of the methanol gave a residue, which was washed with ether to provide crude phosphonium salt 20; δ\_H(300 MHz) 0.97 and 0.99 (each 3H, s, gem-Me), 1.39 (3H, d, J 4, 9-Me), 1.45 (1H, t, J 12, 2-Hax), 1.62 (3H, s, 5-Me), 1.78 (1H, br d, J 12, 2-Heq), 2.03 (1H, br dd, J 16.5 and 9.5, 4-Hax), 2.35 (1H, br dd, J 16.5 and 5.5, 4-Heq), 3.99 (1H, m, 3-H), 4.77 (2H, br dd, J 15.5, 7.5, 11-H2), 5.33 (1H, br q-like, J 7, 10-H), 5.93 (2H, s, 7-H and 8-H), 7.5-7.9 (15H, m, ArH).

Spectral data of compound 1: λ\_max(EtOH)/nm 289 and 475; λ\_max(hexane)/nm 284, 352, 445sh, 466 and 493; ν\_max/cm\(^{-1}\) 3608 (OH), 1654 (conj. CO), 1577, 1555 and 1517 (C=O); δ\_H(500 MHz) 0.84 (3H, s, 1'-Me\_α), 1.08 (6H, s, 1-gem-Me), 1.21 (3H, s, 1'-Me\_β), 1.37 (3H, s, 5'-Me), 1.48 (1H, t, J 12, 2-Hax), 1.49 (1H, dd, J 14.5 and 3.5, 4'-H\_p), 1.71 (1H, dd, J 14 and 5, 2'-H\_p), 1.74 (3H, s, 5-Me), 1.77 (1H, ddd, J 12, 3.5 and 2, 2'-H\_eq), 1.96 (3H, s, 9'-Me), 1.98 (6H, s, 9-Me and 13'-Me), 1.99 (3H, s, 13-Me), 2.00 (1H, dd, J 14 and 7.5, 2'-H\_α), 2.05 (1H, br dd, J 16.5 and 9.5, 4-Hax), 2.39 (1H, ddd, J 16.5, 5.5 and 2, 4-Heq), 2.96 (1H, dd, J 14.5 and 8.5, 4'-H\_p), 4.00 (1H, m, 3-H), 4.51 (1H, m, 3'-H), 6.12 (2H, s, 7-H and 8-H), 6.16 (1H, br d, J 11.5, 10-H), 6.26 (1H, br d, J 11.5, 14-H), 6.35 (1H, br d, J 11, 14'-H), 6.36 (1H, d, J 14.5, 12-H), 6.44 (1H, d, J 15, 7'-H), 6.52 (1H, d, J 14.5, 12'-H), 6.55 (1H, br d, J 11, 10'-H), 6.61 (1H, dd, J 14.5 and 11, 11'-H), 6.63 (1H, dd, J 14 and 11, 15'-H), 6.68 (1H, dd, J 14.5 and 11.5, 11-H), 6.70 (1H, dd, J 14 and 11.5, 15-H), 7.33 (1H, d, J 15, 8'-H); δ\_C(125 MHz) 12.74, 12.79, 12.85 and 12.89 (9-CH\(_3\), 13-CH\(_3\), 9'-CH\(_3\) and 13'-CH\(_3\)).
21.31 (5'-CH₃), 21.63 (5-CH₃), 25.10 (1'-CH₃β), 25.88 (1'-CH₃α), 28.75 and 30.27 (1-gem-Me), 37.14 (C1), 42.59 (C4), 43.98 (C1'), 45.34 (C4'), 48.47 (C2), 50.90 (C2'), 58.95 (C5'), 65.10 (C3), 70.39 (C3'), 120.92 (C7'), 124.11 (C11'), 125.53 (C11), 125.87 (C7), 126.27 (C5), 129.71 (C15'), 134.24 (C10), 131.64 (C15), 132.38 (C14), 133.66 (C9'), 135.25 (C14'), 135.92 (C13'), 136.13 (C9), 137.40 (C12), 137.61 (C13), 137.77 (C6), 138.45 (C8), 140.68 (C10'), 141.96 (C12'), 146.86 (C8'), 202.91 (C6'); CD (dioxane) nm (Δε) 226 (−3.5), 237 (0), 257 (+4.5), 272 (0), 299 (−5.8), 323 (0), 356 (+1.8), 378 (0); m/z (EI) 584.4237 (M⁺, C₄₀H₅₆O₃ requires 584.4226).

Spectral data of compound 2: λ_max(EtOH)/nm 301, 483 and 506sh; λ_max(hexane)/nm 296, 417sh, 442 and 502; ν_max/cm⁻¹ 3612 and 3470 (OH), 1611 (conj. CO), 1584 and 1545 (C=C); δ_H(500 MHz) 0.84 (6H, s, 1-Meα and 1'-Meα), 1.21 (6H, s, 1-Meβ and 1'-Meβ), 1.37 (6H, s, 5-Me and 5'-Me), 1.49 (2H, dd, J 14.5 and 3.5, 4-Hβ and 4'-Hβ), 1.71 (2H, dd, J 13.5 and 4.5, 2-Hβ and 2'-Hβ), 1.96 (6H, s, 9-Me and 9'-Me), 1.99 (6H, s, 13-Me and 13'-Me), 2.00 (2H, dd, J 13.5 and 7.5, 2-Hα and 2'-Hα), 2.96 (2H, dd, J 14.5 and 8.5, 4-Hα and 4'-Hα), 4.51 (2H, m, 3-H and 3'-H), 6.36 (2H, br d-like, J 10, 14-H and 14'-H), 6.45 (2H, d, J 15.5, 7-H and 7'-H), 6.52 (2H, d, J 15, 12-H and 12'-H), 6.55 (2H, br d, J 11.5, 10-H and 10'-H), 6.64 (2H, dd, J 15 and 11.5, 11-H and 11'-H), 6.69 (2H, m, 15-H and 15'-H), 7.33 (2H, d, J 15.5, 8-H and 8'-H); δ(C(125 MHz)) 12.81 and 12.88 (9-CH₃, 13-CH₃, 9'-CH₃ and 13'-CH₃), 21.30 (5-CH₃ and 5'-CH₃), 25.10 (1'-CH₃β and 1'-CH₃α), 25.88 (1'-CH₃α and 1'-CH₃α), 43.98 (C1 and C1'), 45.33 (C4 and C4'), 50.89 (C2 ans C2'), 58.96 (C5 and C5'), 70.36 (C3 and C3'), 121.13 (C7 and C7'), 124.64 (C11 and C11'), 131.21 (C15 and C15'), 134.05 (C9 and C9'), 134.94 (C14 and C14'), 136.97 (C13 and C13'), 140.51 (C10 and C10'), 141.74 (C12 and C12'), 146.76 (C8 and C8'), 202.93 (C6 and C6'); CD (dioxane) nm (Δε) 218 (+0.9), 228 (0), 250 (−0.8), 263 (0), 300 (+3.1), 317 (0), 370 (−1.4); m/z (EI) 600.4179 (M⁺, C₄₀H₅₆O₄ requires 600.4176).