First Total Synthesis of Prorepensin with a Bis-Geranylated Chalcone

Eun Mi Jung and Yong Rok Lee*

School of Chemical Engineering and Technology, Yeungnam University, Gyeongsan 712-749, Korea
**E-mail: yrlee@yu.ac.kr*
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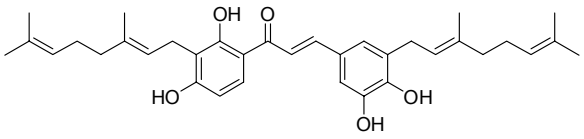
The first total synthesis of naturally occurring prorepensin with a bis-geranylated chalcone has been achieved by a convergent sequence. The key strategy involved in the synthesis of prorepensin was chalcone formation by aldol condensation of the corresponding geranylated acetophenone with geranylated benzaldehyde.

Key Words: Prorepensin, Geranylated chalcone, Aldol reaction

Introduction

Geranylated chalcones are an abundant subclass of flavonoids widely distributed in nature.[1] They have shown a variety of biological properties including antibacterial,[2] antifungal,[3] antitumor,[4] antimetastatic,[5] cancer chemopreventive,[6] anti-HIV,[7] anti-vasoconstriction,[8] and antidiabetic activities[9] and have been used in traditional medicines.[10] Interestingly, it was reported that the presence of the geranyl group in chalcone skeleton leads to a remarkable increase in corresponding bioactivities.[11] These important biological activities and properties have aroused interest in the synthesis of naturally occurring geranylated chalcones. As part of a systematic search for new bioactive lead compounds from African medicinal plants, prorepensin (**1**) was separately isolated from *Dorstenia prorepens* and *D. picta* (Fig. 1).[12]

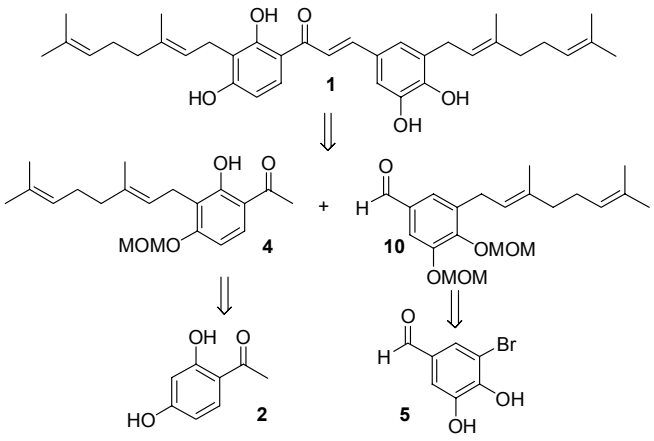


prorepensin (**1**)

Figure 1

This range of important biological activities and properties has stimulated research into the total synthesis of prorepensin (**1**). In particular, no total synthesis of naturally occurring prorepensin (**1**) with a bis-geranylated chalcone has been reported thus far.

Recently, we have developed efficient and useful synthetic routes for preparing pyranochalcones.[13] As part of an ongoing study into the efficacy of such synthetic approaches, the synthesis of prorepensin (**1**) with the bis-geranylated chalcone skeleton has been attempted. We report herein the first total synthesis of the naturally occurring prorepensin (**1**) with a bis-geranylated chalcone.

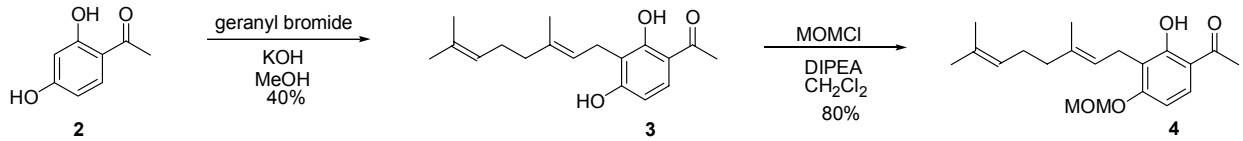


Scheme 1

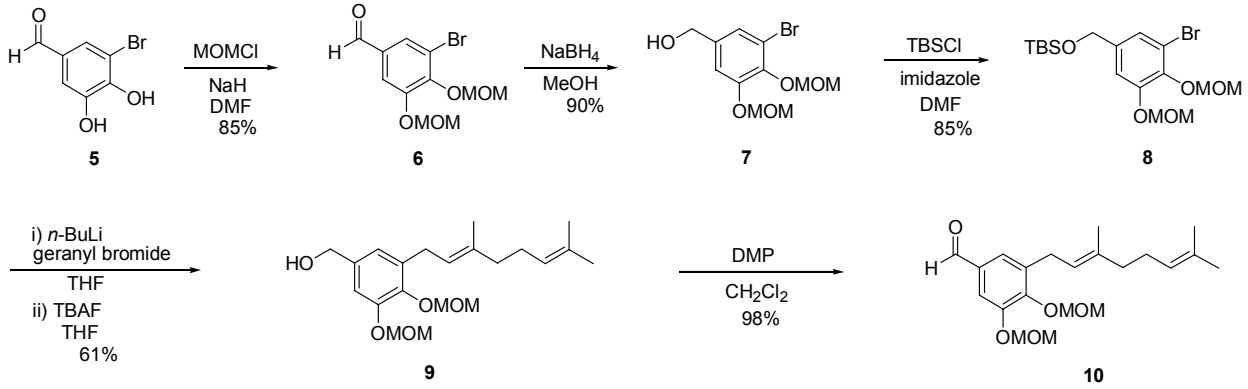
Results and Discussion

Scheme 1 shows the retrosynthetic strategy for the synthesis of prorepensin (**1**). The synthesis of the chalcone structure is readily accomplished through condensation two suitable partners, 3-gernaylated acetophenone **4** and 3-geranylated benzaldehyde **10**. Compound **4**, as the left half, could be generated starting from 2,4-dihydroxyacetophenone (**2**) by a geranylation reaction and selective mono protection of the two phenol groups as a MOM ether. Compound **10**, as the right half, could be prepared from 3-bromo-4,5-dihydroxybenzaldehyde (**5**).

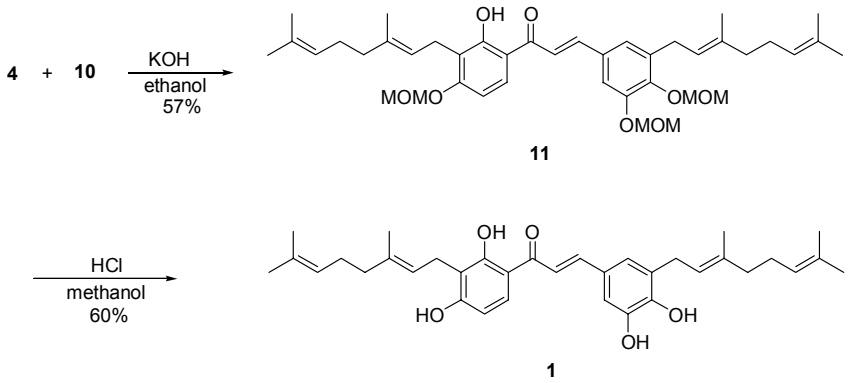
The synthesis of intermediate **4** was first attempted starting from commercially available 2,4-dihydroxyacetophenone (**2**), as shown in Scheme 2. Treatment of 2,4-dihydroxyacetophenone (**2**) and geranyl bromide with KOH in methanol at room



Scheme 2



Scheme 3



Scheme 4

temperature for 24 h afforded geranylated product **3** in 40% yield.[14] Protection of **3** with 1.0 equiv of methoxymethyl chloride in the presence of *N*,*N*-diisopropylethylamine gave **4** in 80% yield. The selective mono methoxymethylation of compound **4** was confirmed by analysis of the ^{1}H NMR spectrum. The signal for the hydroxyl proton in **4** was observed as a singlet associated with a hydrogen bond to a carbonyl group at δ 12.75 ppm. A methoxy signal of the MOM ether was observed as a singlet at δ 3.45 ppm.

As shown in Scheme 3, the synthesis of intermediate **10** as the right half was begun with the readily available 3-bromo-4,5-dihydroxybenzaldehyde (**5**). Reaction of **5** with 2.2 eq of methoxymethyl chloride in the presence of sodium hydride afforded compound **6** in 85% yield. Reduction of **6** with sodium borohydride in methanol gave benzylic alcohol **7** in 90% yield. Treatment of **7** with TBSCl in the presence of imidazole gave silyl ether **8** in 85% yield. Compound **9** was produced in 61% (2 steps) yield by halogen-metal exchange and alkylation reaction using *n*-BuLi with geranyl bromide in THF,[15] followed by cleavage of the silyl ether with TBAF in THF. Oxidation of **9** with Dess-Martin periodinane (DMP) in methylene chloride gave the left half of intermediate **10** in 98% yield.[16]

To complete the total synthesis of natural product prorepensin (**1**), an aldol reaction was next attempted (Scheme 4). Treatment of **4** with aryl benzaldehyde **10** in ethanolic KOH at room temperature for 48 h provided the desired chalcone **11** in 57% yield. Deprotection of **11** with concentrated HCl in methanol at room temperature for 12 h gave prorepensin (**1**) in 60% yield. The spectral data of synthetic material **1** were in agreement with those previously reported.[12a]

In conclusion, the first total synthesis of prorepensin (**1**) has been accomplished by a convergent sequence. The key strategy for the synthesis of prorepensin (**1**) was chalcone formation by an aldol reaction of geranylated acetophenone **4** and geranylated benzaldehyde **10**, prepared separately from 2,4-dihydroxyacetophenone (**2**) and 3-bromo-4,5-dihydroxybenzyl alcohol (**5**).

Experimental Section

All experiments were carried out in a nitrogen atmosphere. Merck pre-coated silica gel plates (Art. 5554) with a fluorescent indicator were used for analytical TLC. Flash column chromatography was performed using silica gel 9385. ^{1}H and ^{13}C NMR spectra were recorded on a Bruker Model ARX (300 and 75 MHz, respectively) spectrometer in $CDCl_3$ as the solvent chemical shift. The IR spectra were recorded on a Jasco FTIR 5300 spectrophotometer. The HRMS spectra were carried out at the Korea Basic Science Institute.

3-Geranyl-2,4-dihydroxyacetophenone (3). To a solution of 2,4-dihydroxyacetophenone **(2)** (2.450 g, 16.1 mmol) in methanol (50 mL) was added geranyl bromide (3.846 g, 17.7 mmol) and anhydrous potassium hydroxide (9.034g, 161.0 mmol). The reaction mixture was stirred at room temperature for 24 h. Evaporation of methanol, addition of 2 N HCl solution (50 mL), and extraction with ethyl acetate (3 × 100 mL),

washing with brine (100 mL), drying over anhydrous $MgSO_4$, and removal of the solvent followed by flash column chromatography on silica gel using hexane/ethylacetate (7:1) gave product **3** (1.875 g, 40%) as a solid: mp 101 - 102 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 13.09 (1H, s), 7.52 (1H, d, *J* = 9.0 Hz), 6.36 (1H, d, *J* = 9.0 Hz), 5.25 (1H, t, *J* = 6.6 Hz), 5.03 (1H, t, *J* = 6.3 Hz), 3.43 (2H, d, *J* = 6.3 Hz), 2.54 (3H, s), 2.15-2.01 (4H, m), 1.80 (3H, s), 1.65 (3H, s), 1.57 (3H, s); ^{13}C NMR (75 MHz, $CDCl_3$) δ 202.8, 162.7, 161.8, 137.3, 131.4, 130.0, 124.0, 121.3, 114.7, 113.4, 107.6, 39.6, 26.4, 25.9, 25.5, 21.4, 17.5, 16.0; IR (KBr) 3167, 2969, 1624, 1449, 1374, 1274, 1163, 1055, 915, 792, 712, 609 cm^{-1}; HRMS *m*/*z* (M^+) calcd for $C_{18}H_{24}O_3$: 288.1725. Found: 288.1722.

1-[3-(3,7-Dimethyl-octa-2,6-dienyl)-2-hydroxy-4-methoxymethoxyphenyl]ethanone (4). Methoxymethyl chloride (0.335 g, 4.2 mmol) was added to a solution of **3** (1.20 g, 4.2 mmol) and *N*,*N*-diisopropylethylamine (3.361 g, 26.0 mmol) in dry CH_2Cl_2 (20 mL). The reaction mixture was stirred at room temperature for 4 h and then water (30 mL) was added. The reaction mixture was extracted with CH_2Cl_2 (3 × 30 mL). The combined organic extracts were washed with saturated NH_4Cl solution (30 mL) and evaporated in vacuo. Flash chromatography on silica gel with hexane/EtOAc (6:1) afforded **4** (1.106 g, 80%) as an oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 12.75 (1H, s), 7.55 (1H, d, *J* = 9.0 Hz), 6.62 (1H, d, *J* = 9.0 Hz), 5.24 (2H, s), 5.20 (1H, t, *J* = 6.3 Hz), 5.04 (1H, t, *J* = 6.3 Hz), 3.45 (3H, s), 3.37 (2H, d, *J* = 6.3 Hz), 2.54 (3H, s), 2.06-1.91 (4H, m), 1.77 (3H, s), 1.61 (3H, s), 1.54 (3H, s); ^{13}C NMR (75 MHz, $CDCl_3$) δ 202.7, 161.7, 160.5, 134.8, 130.8, 129.6, 124.2, 121.7, 117.9, 114.5, 104.6, 93.5, 55.8, 39.6, 26.5, 25.9, 25.4, 21.5, 17.3, 15.8; IR (neat) 2919, 1629, 1496, 1419, 1370, 1260, 1157, 1054, 988, 797, 688 cm^{-1}; HRMS *m*/*z* (M^+) calcd for $C_{20}H_{28}O_4$: 332.1988. Found: 332.1986.

3-Bromo-4,5-dimethoxymethoxybenzaldehyde (6). To a stirred solution of 5-bromo-3,4-dihydroxybenzaldehyde (**5**) (2.0 g, 9.2 mmol) in dry DMF (40 mL) at 0 °C was added sodium hydride (2.20 g, 92.0 mmol) and stirred for 10 min. To the reaction mixture was added methoxymethyl chloride (MOMCl) (1.840 g, 23.0 mmol) slowly and continued the reaction for 1 h. The reaction was quenched by the addition of water (30 mL) and extracted with EtOAc (3 × 50 mL). The organic layer was washed with saturated NH_4Cl solution (30 mL) and then dried over anhydrous Na_2SO_4 and concentrated under reduced pressure to afford crude residue. Flash column chromatography on silica gel with hexane/EtOAc (5:1) afforded **6** (2.380 g, 85%) as an oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.80 (1H, s), 7.70 (1H, s), 7.57 (1H, s), 5.26 (2H, s), 5.22 (2H, s), 3.61(3H, s), 3.46 (3H, s); ^{13}C NMR (75 MHz, $CDCl_3$) δ 189.5, 151.1, 149.2, 133.1, 128.7, 118.3, 115.2, 98.8, 95.1, 58.0, 56.5; IR (neat) 2956, 2833, 1696, 1568, 1478, 1380, 1276, 1158, 1082, 1011, 936, 745, 669 cm^{-1}; HRMS *m*/*z* (M^+) calcd for $C_{11}H_{13}BrO_5$: 303.9946. Found: 303.9948.

3-Bromo-4,5-dimethoxymethoxybenzyl alcohol (7). To a stirred solution of **6** (1.0 g, 3.3 mmol) in methanol (30 mL) at 0 °C was added sodium borohydride (0.186 g, 4.9 mmol) in small portions and continued the reaction for 1 h. The reaction mixture was quenched by the addition of water (30 mL) and extracted with EtOAc (3 × 40 mL). The organic layer was washed with saturated NH_4Cl solution (40 mL) and then dried over anhydrous Na_2SO_4, and concentrated under reduced pressure to afford crude residue. Flash column chromatography on silica gel with hexane/EtOAc (3:1) afforded **7** (0.90 g, 90 %) as an oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.17 (1H, s), 7.05 (1H, s), 5.15 (2H, s), 5.13 (2H, s), 4.54 (2H, s), 3.62(3H, s), 3.45 (3H, s); ^{13}C NMR (75MHz, $CDCl_3$) δ 150.9, 143.2, 138.4, 124.5, 117.8, 114.2, 98.8, 95.2, 64.1, 57.9, 56.4; IR (neat) 3430, 2935, 1569, 1481, 1275, 1157, 1006, 949, 852, 676 cm^{-1}; HRMS *m*/*z* (M^+) calcd for $C_{11}H_{15}BrO_5$: 306.0103. Found: 306.0103.

(3-Bromodimethoxymethoxybenzyloxy)-*t*-butyldimethylsilane (8). To a stirred solution of **7** (0.80 g, 2.6 mmol), in dry DMF (10 mL) at 0 °C was added imidazole (0.443 g, 6.5 mmol) and stirred for 10 - 15 min. TBSCl (0.471 g, 3.1 mmol) was added carefully and the reaction mixture was allowed to stir at room temperature for 10 h. The reaction mixture was quenched by the addition of water (30 mL) and extracted with EtOAc (3 × 30 mL). The organic layer was washed with saturated NH_4Cl solution (30 mL) and then dried over anhydrous Na_2SO_4 and concentrated under reduced pressure to give crude residue. Flash column chromatography on silica gel with hexane/EtOAc (4:1) afforded **8** (0.932 g, 85%) as an oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.14 (1H, s), 7.06 (1H, s), 5.15 (2H, s), 5.14 (2H, s), 4.61 (2H, s), 3.63 (3H, s), 3.46 (3H, s), 0.92 (9H, s), 0.07 (6H, s); ^{13}C NMR (75MHz, $CDCl_3$) δ 150.8, 142.7, 138.9, 123.6, 117.5, 113.5, 98.8, 95.2, 63.9, 57.9, 56.2, 25.9, 18.3, -5.3; IR (neat) 2952, 1570, 1479, 1262, 1158, 1093, 1011, 954, 842, 675 cm^{-1}; HRMS *m*/*z* (M^+) calcd for $C_{17}H_{29}O_5BrSi$: 420.0968. Found: 420.0970.

[3-(3,7-Dimethoxymethoxyocta-2,6-dienyl)-4,5-dimethoxyphenyl]methanol (9). To a solution of **8** (0.80 g, 1.9 mmol) in dry THF (10 mL) at −78 °C were added *n*-BuLi (0.9 mL, 2.5 M in hexane, 2.3 mmol), and the reaction mixture was stirred for 1 h. To the reaction mixture was added geranyl bromide (0.618 g, 2.85 mmol) slowly *via* syringe and continued the reaction at the same temperature for 2 h. Then, the reaction mixture was stirred at 0 °C for 12 h and was quenched by the addition of water (30 mL) and extracted with EtOAc (3 × 30 mL). The organic layer was washed with saturated NH_4Cl solution (30 mL) and then dried over anhydrous Na_2SO_4 and concentrated under reduced pressure to afford crude residue. To the solution of crude residue in THF (10 mL) was added TBAF (1.9 mL, 1.9 mmol, 1.0 M in THF) at 0 °C and stirred at room temperature for 3 h. The reaction mixture was quenched by the addition of saturated NH_4Cl solution (30 mL) and extracted with EtOAc (3 × 30 mL). The organic layer was washed with water (30 mL) and dried over anhydrous Na_2SO_4 and concentrated under reduced pressure to give the crude residue. The resulting crude residue was purified by column chromatography with hexane/EtOAc (4:1) afforded **9** (0.423 g, 61%) as an oil. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.98 (1H, s), 6.81 (1H, s), 5.28 (1H, t, *J* = 7.2 Hz), 5.16 (2H, s), 5.07 (3H, s), 4.55 (2H, s), 3.57 (3H, s), 3.47 (3H, s), 3.40 (2H, d, *J* = 7.2 Hz) 2.14-1.98 (4H, m), 1.69 (3H, s), 1.65 (3H, s), 1.57 (3H, s); ^{13}C NMR (75 MHz, $CDCl_3$) δ 149.6, 143.9, 137.0, 136.1, 135.9, 131.2, 124.1, 122.4, 121.4, 112.6, 98.9, 94.9, 64.8, 57.3, 56.0, 39.6, 28.3, 26.5, 25.5, 17.5, 16.0; IR (neat) 3456, 2924, 1597, 1447, 1297, 1155,

1042 cm^{-1}; HRMS *m/z* (M^+) calcd for $C_{21}H_{32}O_5$: 364.2250. Found: 364.2252.

3,4-Bis(methoxymethoxy)-5-(3,7-diemthylocta-2,6-dienyl) benzaldehyde (10). To a stirred solution of **9** (0.150 g, 0.4 mmol) in dry methylene chloride (10 mL) was added Dess-Martin periodinane (DMP) (0.174 g, 0.4 mmol) at 0 °C, and the reaction mixture was stirred at room temperature for 3 h. The reaction mixture was quenched with saturated sodium bicarbonate (30 mL) and extracted with methylene chloride (3 × 30 mL). The organic layers were washed with saturated sodium thiosulfate (20 mL), water (30 mL) and dried over anhydrous Na_2SO_4 and concentrated under reduced pressure to give the crude residue. The resulting crude residue was purified by column chromatography with hexane/EtOAc (4:1) to afford **10** (0.145 g, 98 %) as an oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.83 (1H, s), 7.49 (1H, d, *J* = 2.0 Hz), 7.36 (1H, d, *J* = 2.0 Hz), 5.30 (1H, t, *J* = 7.0 Hz), 5.22 (2H, s), 5.20 (2H, s), 5.10-5.01 (1H, m), 3.57 (3H, s), 3.47 (3H, s), 3.40 (2H, d, *J* = 7.0 Hz), 2.14-2.01 (4H, m), 1.70 (3H, s), 1.64 (3H, s), 1.57 (3H, s); ^{13}C NMR (75 MHz, $CDCl_3$) δ 191.4, 152.6, 149.5, 137.2, 136.3, 132.4, 131.5, 126.3, 124.1, 121.5, 108.4, 98.8, 57.6, 55.8, 39.6, 28.1, 26.5, 25.6, 17.6, 16.1; IR (neat) 3464, 2933, 1691, 1587, 1460, 1297, 1153, 1078, 959, 767, 624, 476 cm^{-1}; FAB-HRMS *m/z* $[M+H]^+$ calcd for $C_{21}H_{31}O_5$: 363.2171. Found: 363.2167.

Chalcone 11. To a solution of **4** (0.120 g, 0.4 mmol) and **10** (0.131g, 0.4 mmol) in ethanol (10 mL) was added potassium hydroxide (0.203 g, 3.6 mmol) at 0 °C, and the reaction was stirred at room temperature for 48 h. Evaporation of ethanol, addition of 2 N HCl solution (50 mL), and extraction with ethyl acetate (3 × 50 mL), washing with brine (50 mL), drying over anhydrous $MgSO_4$, and removal of the solvent followed by flash column chromatography on silica gel using hexane/ethylacetate (20:1) afforded **11** (0.139 g, 57%) as an oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 13.42 (1H, s), 7.77 (1H, d, *J* = 15.0 Hz), 7.73 (1H, d, *J* = 8.7 Hz), 7.43 (1H, d, *J* = 15.0 Hz), 7.28 (1H, s), 7.12 (1H, s), 6.67 (1H, d, *J* = 8.7 Hz), 5.33-5.22 (2H, m), 5.25 (2H, s), 5.22 (2H, s), 5.15 (2H, s), 5.15-5.01 (2H, m), 3.59 (3H, s), 3.52 (3H, s), 3.46 (3H, s), 3.46-3.39 (4H, m), 2.21-1.93 (8H, m), 1.79 (3H, s), 1.72 (3H, s), 1.65 (3H, s), 1.62 (3H, s), 1.58 (3H, s), 1.55 (3H, s); ^{13}C NMR (75 MHz, $CDCl_3$) δ 192.2, 163.2, 160.6, 149.9, 147.1, 144.2, 136.9, 136.4, 135.1, 131.4, 131.0, 130.7, 128.7, 124.3, 124.2, 124.0, 121.8, 119.4, 118.4, 114.9, 113.5, 104.7, 98.9, 95.1, 93.7, 57.4, 56.2, 56.0, 39.7, 28.2, 26.6, 25.6, 21.7, 17.6, 17.5, 16.1, 16.0; IR (neat) 2961, 2918, 2852, 2074, 1728, 1633, 1582, 1487, 1433, 1371, 1264, 1155, 1109, 1078, 1046, 960, 795, 661, 609 cm^{-1}; FAB-HRMS *m/z* $[M+H]^+$ calcd for $C_{41}H_{57}O_8$: 677.4053. Found: 677.4056.

Prorepensin (1). To a solution of chalcone **11** (0.050 g, 0.1 mmol) in methanol (5 mL) was added c- HCl (5 drops) at 0 °C, and the reaction mixture was stirred at room temperature for 12 h. The reaction mixture was diluted with saturated $NaHCO_3$ solution (30 mL) and extracted with EtOAc (3 × 30 mL). Removal of solvent at reduced pressure left an oily residue, which was then purified by column chromatography on silica gel with hexane/EtOAc (2:1) to give **1** (0.024 g, 60%) as an oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 13.89 (1H, s), 7.72 (1H, d, *J* = 15. 3 Hz), 7.66 (1H, d, *J* = 9.0 Hz), 7.36 (1H, d, *J* = 15.3 Hz), 7.06 (1H, s), 6.94 (1H, s), 6.39 (1H, d, *J* = 9.0 Hz), 5.34-5.26 (2H, m), 5.14-5.01 (2H, m), 3.46 (2H, d, *J* = 7.2 Hz), 3.37 (2H, d, *J* = 7.2 Hz), 2.20-2.01 (8H, m), 1.80 (3H, s), 1.75 (3H, s), 1.66 (3H, s), 1.65 (3H, s), 1.59 (3H, s), 1.58 (3H, s); ^{13}C NMR (75 MHz, $CDCl_3$) δ 192.3, 163.8, 161.8, 145.1, 144.8, 144.2, 139.4, 139.0, 132.1, 132.0, 129.3, 127.8, 127.3, 123.7, 123.6, 121.1, 120.8, 117.9, 114.2, 113.9, 112.4, 107.9, 39.7, 39.6, 29.3, 26.4, 26.3 25.7, 25.6, 21.7, 17.7, 17.6, 16.2, 16.1; IR (neat) 3408, 2918, 2357, 1609, 1492, 1440, 1378, 1277, 1105, 1040, 976, 846, 801, 739, 622 cm^{-1}; FAB-HRMS *m/z* $[M+H]^+$ calcd for $C_{35}H_{45}O_5$: 545.3267. Found: 545.3264.

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