Supporting Information

Gold(I)-Catalyzed Intramolecular Hydroarylation and the Subsequent Ring Enlargement of Methyleneacycloprenes to Cyclobutenes

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1. **General Remarks.** MP was obtained with a Yanagimoto micro melting point apparatus and is uncorrected. \( ^1 \)H NMR spectra were recorded for solution in CDCl\(_3\) with tetramethylsilane (TMS) as internal standard. \( J \)-values are in Hz. HRMS was measured by a Finnigan MA+ mass spectrometer. Organic solvents used were dried by standard methods when necessary. Commercially obtained reagents were used without further purification. All reactions were monitored by TLC with Huanghai GF\(_{254}\) silica gel coated plates. Flash column chromatography was carried out using 300-400 mesh silica gel at increased pressure. All reactions were performed under argon using standard Schlenk techniques.
2. General procedure for the synthesis of methylenecyclopropanes 1a-j.

Salicylaldehyde (10.0 mmol, 1.0 equiv) was suspended in acetonitrile (40 mL), followed by addition of K$_2$CO$_3$ (20.0 mmol, 2.0 equiv). The suspension was stirred for 10 min, and then propargyl bromide (1.5 equiv) was added via a syringe at 60 °C. The reaction mixture was stirred for 6 hours at 60 °C, whereupon a brown mixture was obtained. The crude product was collected by filtration, then purified by silica gel chromatography (PE:EA = 25:1) to get the o-(propargyloxy)-benzaldehyde in over 90% yield.[1]

To a suspension of sodium hydride (15.0 mmol, 3.0 equiv) in THF (30 mL) was added (3-bromo-propyl)-triphenylphosphonium bromide (7.5 mmol, 1.5 equiv) and the mixture was stirred for 12 hours under reflux, then a solution of aldehyde (5.0 mmol, 1.0 equiv) in THF (20 mL) was added to the mixture and stirred for another 12 hours. The reaction was quenched with water and extracted with petroleum ether. The organic layer was washed with brine and dried over anhydrous Na$_2$SO$_4$, then the solvent was removed under reduced pressure and the residue was purified by silica gel chromatography (PE) to give methylenecyclopropane 1a-h in about 35% yield.[2]

3. General procedure for the synthesis of methylenecyclopropanes 1k.

To a solution of methylenecyclopropane 1a (1.8 mmol, 1.0 equiv) in THF (20 mL) was added n-butyllithium (1.98 mmol, 1.1 equiv) via a syringe at -78 °C. The reaction mixtures were stirred
at that temperature for 2 hours. Then, ethyl chloroformate (1.98 mmol, 1.1 equiv) was added to
the mixture and the reaction vessel was naturally warmed to room temperature. The reaction
mixture was stirred at room temperature for another 12 hours. After that, the resulting mixture
was quenched with water (10 mL) and extracted with ethyl acetate (25 mL) three times. The
organic layer was washed with brine and dried over anhydrous Na₂SO₄, then the solvent was
removed under reduced pressure and the residue was purified by silica gel chromatography
(PE:EA = 10:1) to give methylenecyclobutane 1k in 22% yield.

4. General procedure for the synthesis of methylenecyclobutane 1i.

To a suspension of (4-bromo-butyl)-triphenylphosphonium bromide (10 mmol, 1.0 equiv) in
ethyl ether (50 mL) was added n-butyllithium (11 mmol, 1.1 equiv) and the mixture was stirred
for 24 hours under reflux, then n-butyllithium (11 mmol, 1.1 equiv) was added to the mixture and
stirred for another 1 hour then a solution of aldehyde (10 mmol, 1.0 equiv) in ethyl ether (20 mL)
was added to the mixture and stirred for another 1 hour. The reaction was quenched with water
and extracted with petroleum ether. The organic layer was washed with brine and dried over
anhydrous Na₂SO₄, then the solvent was removed under reduced pressure and the residue was
purified by silica gel chromatography (PE) to give methylenecyclobutanes 1l’ and 1m in 32% and
36% yield, respectively.[3]

methylene cyclobutane 1l’ (3.2 mmol, 1.0 equiv) was suspended in methanol (10 mL),
followed by addition of K₂CO₃ (6.4 mmol, 2.0 equiv). The suspension was stirred for 2 hours at
room temperature. The reaction was extracted with petroleum ether. The organic layer was
washed with brine and dried over anhydrous Na₂SO₄, then the solvent was removed under
reduced pressure and the residue was purified by silica gel chromatography (PE) to give
methylenecyclobutane 1l in 92% yield.

5. General procedure for the synthesis of 2.
To a flame-dried flask were added the methylenecyclopropane (or methylenecyclobutane) (0.2 mmol, 1.0 equiv) and the \((p\text{-CF}_{3}C_{6}H_{4})_{3}PAuSbF_{6}\) (0.005 mmol, 0.025 equiv), the flask was evacuated and backfilled with Ar for 3 times. DCE (2.0 mL) was added to this flask via a syringe under Ar. The reaction mixture was stirred for 3 hours at room temperature. Appropriate amount of silica gel was added to the reaction mixture and the solvent was removed under vacuum pump at low temperature, the crude product was purified by silica gel chromatography (PE) to get the desired product 2.


To a flame-dried flask were added the methylenecyclopropane (0.2 mmol, 1.0 equiv) and the IPrAuSbF\(_6\) (0.005 mmol, 0.025 equiv), the flask was evacuated and backfilled with Ar for 3 times. DCE (2.0 mL) was added to this flask via a syringe under Ar. The reaction mixture was stirred for 4 hours at 90 °C. Appropriate amount of silica gel was added to the reaction mixture and the solvent was removed under vacuum pump at low temperature, the crude product was purified by silica gel chromatography (PE) to get the desired product 3.

7. Characterization and spectra charts

Compound 1a. 662 mg, yield: 36%; colorless oil. \(^1\)H NMR (CDCl\(_3\), 400 MHz, TMS) \(\delta\) 1.13-1.17 (m, 2H, CH\(_2\)), 1.35-1.39 (m, 2H, CH\(_2\)), 2.48 (t, \(J = 2.4\) Hz, 1H, CH), 4.69 (d, \(J = 2.4\) Hz, 2H, CH\(_2\)), 6.96-6.99 (m, 2H, =CH, Ar), 7.14-7.20 (m, 2H, Ar), 7.76 (dd, \(J_1 = 8.0\) Hz, \(J_2 = 1.6\) Hz, 1H,
Compound 2a. 32 mg, yield: 86%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 1.14-1.18 (m, 2H, CH$_2$), 1.36-1.40 (m, 2H, CH$_2$), 4.85 (dd, $J_1 = 3.6$ Hz, $J_2 = 2.0$ Hz, 2H, CH$_2$), 5.79 (dt, $J_1 = 9.6$ Hz, $J_2 = 3.6$ Hz, 1H, =CH), 6.42 (d, $J = 9.6$ Hz, 1H, =CH), 6.83-6.84 (m, 2H, Ar), 7.05 (s, 1H, =CH), 7.58 (dd, $J_1 = 4.8$ Hz, $J_2 = 4.8$ Hz, 1H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 0.6, 3.9, 65.5, 111.6, 120.9, 121.8, 122.5, 124.5, 124.9, 125.0, 125.7, 126.3, 150.5. IR (neat) v 3291, 3046, 2846, 2123, 1784, 1638, 1581, 1460, 1323, 1237, 1199, 1086, 975, 745 cm$^{-1}$. MS (%) m/e 184 (M$^+$, 84.89), 183 (100.00), 169 (34.64), 155 (37.71), 141 (35.89), 128 (37.02), 115 (56.60), 103 (22.53), 91 (25.02), 80 (16.13), 77 (8.85), 63 (8.26), 51 (9.43), 41 (12.37), 39 (16.34), 31 (12.12). HRMS (EI) calcd. for C$_{13}$H$_{12}$O: 184.0888, found: 184.0883.
Compound 3a. 35 mg, yield: 94%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 2.55-2.57 (m, 2H, CH$_2$), 2.82-2.83 (m, 2H, CH$_2$), 4.88 (dd, $J_1 = 3.6$ Hz, $J_2 = 2.0$ Hz, 2H, CH$_2$), 5.76 (dt, $J_1 = 10.0$ Hz, $J_2 = 3.6$ Hz, 1H, =CH), 6.32 (s, 1H, =CH), 6.40 (d, $J = 10.0$ Hz, 1H, =CH), 6.79-6.84 (m, 2H, Ar), 7.01 (dd, $J_1 = 7.6$ Hz, $J_2 = 2.4$ Hz, 1H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 27.5, 29.9, 65.4, 120.6, 121.6, 122.1, 122.5, 124.6, 125.7, 126.4, 132.0, 142.5, 152.4. IR (neat) $\nu$ 3048, 2919, 2849, 1639, 1594, 1460, 1392, 1235, 1215, 1079, 1017, 927, 805, 750, 698 cm$^{-1}$. MS (%) m/e 184 (M$^+$, 100.00), 169 (42.04), 155 (56.12), 141 (30.97), 128 (47.38), 115 (50.82), 102 (15.29), 91 (23.72), 51 (22.85). HRMS (EI) calcd. for C$_{13}$H$_{12}$O: 184.0888, found: 184.0882.
Compound 1b. 1.215 g, yield: 64%; white solid. MP: 48-49 °C. ¹H NMR (CDCl₃, 400 MHz, TMS) δ 1.13-1.17 (m, 2H, CH₂), 1.37-1.42 (m, 2H, CH₂), 2.30 (s, 1H, CH₃), 2.49 (t, J = 2.4 Hz, 1H, CH), 4.69 (d, J = 2.4 Hz, 2H, CH₂), 6.89 (d, J = 8.4 Hz, 1H, Ar), 6.98 (dd, J₁ = 8.4 Hz, J₂ = 2.0 Hz, 1H, Ar), 7.11 (dd, J₁ = 2.0 Hz, J₂ = 2.0 Hz, 1H, Ar), 7.56 (s 1H, =CH). ¹³C NMR (CDCl₃, 100 MHz, TMS) δ 0.6, 4.0, 20.8, 56.7, 75.2, 79.0, 112.0, 113.1, 124.4, 127.2, 127.5, 128.0, 130.9, 152.2. IR (neat) ν 3287, 2953, 2856, 2121, 1731, 1607, 1587, 1495, 1455, 1376, 1260, 1163, 1070, 923, 802 cm⁻¹. MS (%) m/e 198 (M⁺, 4.41), 183 (8.10), 159 (100.00), 143 (13.65), 131 (21.09), 115 (45.50), 91 (36.26), 77 (17.61), 51 (10.04). HRMS (EI) calcd. for C₁₄H₁₆O: 198.1045, found: 198.1046.
Compound 2b. 31 mg, yield: 78%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) δ 1.13-1.17 (m, 2H, CH$_2$), 1.36-1.41 (m, 2H, CH$_2$), 2.25 (s, 3H, CH$_3$), 4.81 (dd, $J_1 = 3.6$ Hz, $J_2 = 2.0$ Hz, 2H, CH$_2$), 5.78 (dt, $J_1 = 9.6$ Hz, $J_2 = 3.6$ Hz, 1H), 6.39 (dt, $J_1 = 9.6$ Hz, $J_2 = 2.0$ Hz, 1H), 6.66 (d, $J = 2.0$ Hz, 1H), 7.02 (dd, $J_1 = 4.0$ Hz, $J_2 = 2.0$ Hz, 1H), 7.38 (s, 1H). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) δ 0.6, 4.0, 20.7, 65.5, 111.6, 121.9, 122.4, 124.1, 125.0, 125.3, 125.7, 126.5, 129.9, 148.4. IR (neat) ν 3045, 2973, 2826, 1638, 1468, 1425, 1245, 1240, 1209, 1154, 1037, 1024, 937, 860, 773, 694 cm$^{-1}$. MS (%) m/e 198 (M$^+$, 76.49), 183 (100.00), 169 (17.35), 155 (32.75), 153 (36.67), 128 (46.89), 115 (53.56), 91 (31.28), 77 (27.44). HRMS (EI) calcd. for C$_{14}$H$_{14}$O: 198.1045, found: 198.1040.
Compound 3b. 18 mg, yield: 45%; colorless oil. \(^1\)H NMR (CDCl\(_3\), 400 MHz, TMS) \(\delta\) 2.23 (s, 3H, CH\(_3\)), 2.54-2.56 (m, 2H, CH\(_2\)), 2.81-2.82 (m, 2H, CH\(_2\)), 4.84 (dd, \(J_1 = 3.6\) Hz, \(J_2 = 1.6\) Hz, 2H, CH\(_2\)), 5.76 (dt, \(J_1 = 10.0\) Hz, \(J_2 = 3.6\) Hz, 1H, =CH), 6.31 (s, 1H, =CH), 6.37 (dt, \(J_1 = 10.0\) Hz, \(J_2 = 1.6\) Hz, 1H, =CH), 6.66 (s, 1H, Ar), 6.81 (s, 1H, Ar). \(^{13}\)C NMR (CDCl\(_3\), 100 MHz, TMS) \(\delta\) 20.5, 27.4, 29.9, 65.3, 121.7, 122.0, 122.2, 124.7, 126.3, 126.7, 129.7, 131.9, 142.6, 150.3. IR (neat) \(\nu\) 2915, 2833, 1713, 1675, 1583, 1469, 1379, 1238, 1217, 1132, 1035, 914, 861, 752, 694 cm\(^{-1}\). MS (\(%)\) m/e 198 (M\(^+\), 100.00), 183 (77.19), 155 (43.30), 128 (41.48), 115 (44.44), 91 (26.40), 77 (24.78), 63 (16.42), 51 (15.88). HRMS (EI) calcd. for C\(_{14}\)H\(_{14}\)O: 198.1045, found: 198.1049.
Compound 1c. 426 mg, yield: 21%; white solid. MP: 63-64 °C. 1H NMR (CDCl₃, 400 MHz, TMS) δ 1.13-1.17 (m, 2H, CH₂), 1.34-1.39 (m, 2H, CH₂), 2.35 (s, 3H, CH₃), 2.51 (t, J = 2.4 Hz, 1H, CH), 4.71 (d, J = 2.4 Hz, 2H, CH₂), 6.80 (d, J = 4.4 Hz, 2H, Ar), 7.1 (s, 1H, =CH₂), 7.65 (dd, J₁ = 4.4 Hz, J₂ = 4.4 Hz, 1H, Ar). 13C NMR (CDCl₃, 100 MHz, TMS) δ 0.6, 3.9, 21.5, 56.4, 75.3, 78.9, 111.9, 113.6, 122.4, 123.5, 125.0, 126.6, 137.6, 154.1. IR (neat) ν 3286, 2920, 2864, 2122, 1777, 1735, 1611, 1504, 1452, 1364, 1287, 1191, 1080, 971, 815 cm⁻¹. MS (%) m/e 198 (M⁺, 4.48), 183 (8.33), 159 (100.00), 143 (13.57), 128 (21.70), 115 (45.61), 91 (35.15), 77 (17.66), 51 (9.68). HRMS (EI) calcd. for C₁₄H₁₄O: 198.1045, found: 198.1040.
Compound 2c. 29 mg, yield: 73%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 1.12-1.15 (m, 2H, CH$_2$), 1.33-1.37 (m, 2H, CH$_2$), 2.27 (s, 3H, CH$_3$), 4.76 (dd, $J_1 = 3.6$ Hz, $J_2 = 2.4$ Hz, 2H, CH$_2$), 5.84 (dt, $J_1 = 10.0$ Hz, $J_2 = 3.6$ Hz, 1H, =CH), 6.62 (d, $J = 10.0$ Hz, 1H, =CH), 6.70 (d, $J = 8.0$ Hz, 1H, Ar), 7.03 (s, 1H,=CH), 7.49 (d, $J = 8.0$ Hz, 1H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 0.5, 3.8, 18.4, 64.7, 111.7, 121.0, 121.5, 122.2, 122.7, 123.3, 123.7, 125.7, 123.7, 125.7, 132.6, 150.6. IR (neat) $\nu$ 3046, 2972, 2853, 1782, 1595, 1488, 1459, 1255, 1203, 1088, 1021, 941, 827, 732, 693 cm$^{-1}$. MS (%) m/e 198 (M$^+$, 44.83), 183 (100.00), 153 (27.02), 128 (26.20), 115 (30.45), 91 (21.90), 77 (15.28), 63 (8.19), 51 (9.17). HRMS (EI) calcd. for C$_{14}$H$_{14}$O: 198.1045, found: 198.1040.
Compound 3c. 25 mg, yield: 63%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 2.27 (s, 3H, CH$_3$), 2.55 (s, 2H, CH$_2$), 2.80-2.81 (m, 2H, CH$_2$), 4.80 (dd, $J_1$ = 3.6 Hz, $J_2$ = 2.0 Hz, 2H, CH$_2$), 5.83 (dt, $J_1$ = 10.0 Hz, $J_2$ = 3.6 Hz, 1H, =CH), 6.27 (s, 1H, =CH), 6.60 (dd, $J_1$ = 10.0 Hz, $J_2$ = 2.0 Hz, 1H, =CH), 6.67 (d, $J$ = 8.0 Hz, 1H, Ar), 6.92 (d, $J$ = 8.0 Hz, 1H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 18.5, 27.4, 29.8, 64.6, 120.7, 120.8, 121.3, 121.9, 122.3, 125.8, 130.8, 133.4, 142.6, 152.6. IR (neat) ν 2976, 2917, 2834, 1780, 1705, 1642, 1952, 1454, 1381, 1213, 1087, 1046, 879, 748, 697 cm$^{-1}$. MS (%) m/e 198 (M$^+$, 100.00), 183 (79.41), 155 (48.78), 128 (40.68), 115 (40.74), 91 (20.32), 77 (18.41), 63 (12.31), 51 (11.99). HRMS (EI) calcd. for C$_{14}$H$_{14}$O: 198.1045, found: 198.1047.
Compound 1d. 495mg, yield: 26%; white solid. MP: 43-45 °C. 

1H NMR (CDCl₃, 400 MHz, TMS) δ 1.16-1.20 (m, 2H, CH₂), 1.38-1.42 (m, 2H, CH₂), 2.51 (t, J = 2.4 Hz, 1H, CH), 4.69 (d, J = 2.4 Hz, 2H, CH₂), 6.84-6.89 (m, 1H), 6.94 (dd, J₁ = 9.2 Hz, J₂ = 4.8 Hz, 1H), 7.09 (s 1H), 7.46 (dd, J₁ = 9.2 Hz, J₂ = 2.0 Hz, 1H).

13C NMR (CDCl₃, 100 MHz, TMS) δ 0.6, 3.8, 57.2, 75.6, 78.6, 111.3 (d, J_C-F = 1.9 Hz), 112.8 (d, J_C-F = 24.0 Hz), 113.5 (d, J_C-F = 23.5 Hz), 114.5 (d, J_C-F = 8.8 Hz), 126.3 (d, J_C-F = 0.7 Hz), 129.6 (d, J_C-F = 7.6 Hz), 150.3 (d, J_C-F = 2.3 Hz), 157.9 (d, J_C-F = 237.6 Hz).

19F NMR (376 MHz, CDCl₃, CFCl₃): δ -122.24 ~ -122.17 (m, 1F). IR (neat) v 3296, 3077, 2921, 2871, 1769, 1732, 1611, 1491, 1372, 1237, 1182, 1066, 987, 805 cm⁻¹. MS (%) m/e 202 (M⁺, 2.68), 163 (100.00), 147 (10.13), 133 (41.85), 115 (47.97), 109 (25.59), 75 (9.72), 57 (9.90), 51 (5.98). HRMS (EI) calcd. for C₁₃H₁₁OF: 202.0794, found: 202.0791.
Compound 2d. 33 mg, yield: 80%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 1.14-1.18 (m, 2H, CH$_2$), 1.36-1.40 (m, 2H, CH$_2$), 4.81 (dd, $J_1$ = 3.6 Hz, $J_2$ = 2.0 Hz, 2H, CH$_2$), 5.85 (dt, $J_1$ = 9.6 Hz, $J_2$ = 3.6 Hz, 1H, =CH), 6.36 (d, $J$ = 9.6 Hz, 1H, =CH), 6.55 (dd, $J_1$ = 8.0 Hz, $J_2$ = 2.8 Hz,
1H, Ar), 7.02 (d, J = 1.6 Hz, 1H, =CH), 7.26 (dd, J₁ = 9.6 Hz, J₂ = 2.8 Hz, 1H, Ar). ¹³C NMR (CDCl₃, 100 MHz, TMS) δ 0.5, 3.8, 65.5, 111.0 (d, J_C-F = 2.2 Hz), 111.2 (d, J_C-F = 23.9 Hz), 111.6 (d, J_C-F = 23.5 Hz), 123.4, 123.5 (d, J_C-F = 8.7 Hz), 124.4 (d, J_C-F = 2.2 Hz), 125.8 (d, J_C-F = 0.8 Hz), 127.0 (d, J_C-F = 8.0 Hz), 146.4 (d, J_C-F = 2.3 Hz), 157.3 (d, J_C-F = 236.1 Hz). ¹⁹F NMR (376 MHz, CDCl₃, CFCl₃): δ -123.34 ~ -123.29 (m). IR (neat) ν 3050, 2975, 2845, 1594, 1465, 1446, 1301, 1209, 1196, 1129, 1039, 997, 861, 775, 692 cm⁻¹. MS (%) m/e 202 (M⁺, 100.00), 201 (99.36), 187 (40.34), 173 (36.62), 159 (39.49), 146 (40.31), 133 (68.39), 115 (17.54), 51 (13.69). HRMS (EI) calcd. for C_{13}H_{11}OF: 202.0794, found: 202.0792.
Compound 3d. 17 mg, yield: 41%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 2.56 (s, 2H, CH$_2$), 2.78-2.80 (m, 2H, CH$_2$), 4.85 (dd, $J_1 = 3.6$ Hz, $J_2 = 2.0$ Hz, 2H, CH$_2$), 5.84 (dt, $J_1 = 9.6$ Hz, $J_2 = 3.6$ Hz, 1H, =CH), 6.34-6.37 (m, 2H, =CH, Ar), 6.56 (dd, $J_1 = 8.0$ Hz, $J_2 = 2.8$ Hz, 1H, Ar), 6.68 (dd, $J_1 = 9.6$ Hz, $J_2 = 2.8$ Hz, 1H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 27.4, 29.8, 65.4, 111.6 (d, $J_{C-F} = 23.6$ Hz), 112.0 (d, $J_{C-F} = 23.6$ Hz), 123.1, 123.2 (d, $J_{C-F} = 8.4$ Hz), 123.6 (d, $J_{C-F} = 7.2$ Hz), 124.1 (d, $J_{C-F} = 2.2$ Hz), 133.5, 141.6 (d, $J_{C-F} = 1.9$ Hz), 148.3 (d, $J_{C-F} = 1.9$ Hz), 157.0 (d, $J_{C-F} = 236.5$ Hz). $^{19}$F NMR (376 MHz, CDCl$_3$, CFCl$_3$): $\delta$ -123.91 $-$ -123.86 (m, 1F). IR (neat) $\nu$ 2916, 2833, 1713, 1675, 1588, 1467, 1446, 1314, 1204, 1155, 1035, 978, 854, 750, 693 cm$^{-1}$. MS (%) m/e 202 (M$^+$, 100.00), 187 (43.38), 173 (47.66), 159 (32.14), 146 (38.14), 133 (43.72), 101 (11.79), 75 (14.08), 51 (11.38). HRMS (EI) calcd. for C$_{13}$H$_{11}$OF: 202.0794, found: 202.0795.
Compound 1e. 1.015 g, yield: 47%; white solid. MP: 77-79 °C

$\text{H NMR (CDCl}_3, 400 \text{ MHz, TMS)}$

$\delta$ 1.16-1.20 (m, 2H, CH$_2$), 1.39-1.44 (m, 2H, CH$_2$), 2.52 (t, $J = 2.4$ Hz, 1H, CH), 4.71 (d, $J = 2.4$ Hz, 2H, CH$_2$), 6.92 (d, $J = 8.8$ Hz, 1H, Ar), 7.07 (s, 1H, =CH), 7.13 (dd, $J_1 = 8.8$ Hz, $J_2 = 2.4$ Hz, 1H, Ar), 7.70 (d, $J = 2.4$ Hz, 1H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 0.7, 3.9, 56.7, 75.8, 78.3, 111.0, 114.1, 126.4, 126.5, 126.9, 127.0, 129.4, 152.6. IR (neat) $\nu$ 3293, 3076, 2954, 2924, 2123, 1770, 1716, 1592, 1482, 1452, 1223, 1123, 1021, 801, 733 cm$^{-1}$. MS (%) m/e 218 (M$^+$, 2.80), 183 (23.42), 179 (84.28), 155 (10.00), 144 (24.61), 115 (100.00), 89 (18.95), 75 (15.53), 51 (9.33). HRMS (EI) calcd. for C$_{13}$H$_{11}$OCl: 218.0498, found: 218.0499.
Compound 2e. 42 mg, yield: 95%; colorless oil. \(^1\)H NMR (CDCl\(_3\), 400 MHz, TMS) \(\delta\) 1.14-1.18 (m, 2H, \(\text{CH}_2\)), 1.37-1.42 (m, 2H, \(\text{CH}_2\)), 4.84 (dd, \(J_1 = 3.6\) Hz, \(J_2 = 2.0\) Hz, 2H, \(\text{CH}_2\)), 5.82 (dt, \(J_1 = 9.6\) Hz, \(J_2 = 3.6\) Hz, 1H, =CH), 6.34 (d, \(J = 9.6\) Hz, 1H, =CH), 6.79 (d, \(J = 2.4\) Hz, 2H, Ar), 6.97 (t, \(J = 2.0\) Hz, 1H, =CH), 7.51 (d, \(J = 2.4\) Hz, 1H, Ar). \(^13\)C NMR (CDCl\(_3\), 100 MHz, TMS) \(\delta\) 0.6, 3.9, 65.6, 111.7, 123.1, 123.7, 124.0, 124.3, 125.4, 125.9, 126.0, 127.2, 148.9. IR (neat) \(\nu\) 3051, 2974, 2974, 2850, 2005, 1778, 1463, 1422, 1328, 1200, 1023, 990, 867, 736 cm\(^{-1}\). MS (%) m/e 218 (M\(^+\), 10.17), 183 (100.00), 153 (24.09), 128 (13.86), 115 (18.62), 102 (4.23), 91 (7.34), 77 (9.48), 51 (7.61). HRMS (EI) calcd. for C\(_{13}\)H\(_{11}\)OCl: 218.0498, found: 218.0496.
Compound 3e. 28 mg, yield: 64%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 2.55-2.56 (m, 2H, CH$_2$), 2.78-2.80 (m, 2H, CH$_2$), 4.88 (dd, $J_1 = 3.6$ Hz, $J_2 = 2.0$ Hz, 2H, CH$_2$), 5.80 (dt, $J_1 = 10.0$ Hz, $J_2 = 3.6$ Hz, 1H, =CH), 6.33 (dt, $J_1 = 10.0$ Hz, $J_2 = 2.0$ Hz, 1H, =CH), 6.35 (s, 1H, =CH), 6.79 (d, $J = 2.4$ Hz, 1H, Ar), 6.94 (d, $J = 2.4$ Hz, 1H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 27.5, 29.8, 65.5, 122.8, 123.4, 123.7, 123.9, 124.9, 125.5, 125.7, 133.6, 141.3, 150.8. IR (neat) v 3051, 2914, 2832, 1733, 1678, 1567, 1465, 1449, 1306, 1252, 1212, 1137, 1034, 915, 863, 747 cm$^{-1}$. MS (%) m/e 218 (M$^+$, 84.62), 183 (100.00), 155 (81.27), 128 (42.57), 115 (38.45), 102 (16.57), 91 (17.82), 76 (42.16), 51 (35.02). HRMS (EI) calcd. for C$_{13}$H$_{11}$OCl: 218.0498, found: 218.0493.
Compound 1f. 857 mg, yield: 35%; white solid. MP: 91-92 °C. 1H NMR (CDCl₃, 400 MHz, TMS) δ 1.16-1.20 (m, 2H, CH₂), 1.40-1.44 (m, 2H, CH₂), 2.52 (t, J = 2.0 Hz, 1H, CH), 4.70 (d, J = 2.0 Hz, 2H, CH₂), 6.87 (d, J = 8.4 Hz, 1H, Ar), 7.05 (d, J = 2.0 Hz, 1H, =CH), 7.27 (dd, J₁ = 8.4 Hz, J₂ = 2.4 Hz, 1H, Ar), 7.84 (d, J = 2.4 Hz, 1H, Ar). 13C NMR (CDCl₃, 100 MHz, TMS) δ 0.7, 3.9, 56.5, 75.8, 78.3, 110.9, 114.4, 114.5, 126.5, 129.3, 129.9, 130.0, 153.1. IR (neat) ν 3292, 3075, 2953, 2868, 2122, 1769, 1734, 1589, 1481, 1373, 1222, 1114, 1021, 926, 801 cm⁻¹. MS (%) m/e 262 (M⁺, 1.93), 223 (45.97), 183 (17.12), 168 (27.21), 155 (11.12), 144 (46.22), 115 (100.00), 89 (17.12), 51 (9.52). HRMS (EI) calcd. for C_{13}H₁₁OBr: 261.9993, found: 261.9999.
Compound 2f. 34 mg, yield: 64%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 1.14-1.18 (m, 2H, CH$_2$), 1.38-1.42 (m, 2H, CH$_2$), 4.84-4.85 (m, 2H, CH$_2$), 5.82 (dt, $J_1$ = 9.6 Hz, $J_2$ = 3.6 Hz, 1H, =CH), 6.34 (d, $J$ = 9.6 Hz, 1H, =CH), 6.93-6.96 (m, 2H, =CH, Ar), 7.65 (d, $J$ = 2.4 Hz, 1H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 0.6, 3.9, 65.6, 110.6, 113.4, 123.1, 123.9, 124.2, 126.0, 127.2, 127.7, 128.4, 149.4. IR (neat) $\nu$ 2922, 2850, 1780, 1640, 1570, 1463, 1449, 1421, 1254, 1201, 1070, 935, 840, 769, 694 cm$^{-1}$. MS (%) m/e 262 (M$^+$, 8.42), 183 (100.00), 153 (27.53), 128 (20.86), 115 (22.92), 102 (5.52), 91 (17.80), 77 (16.03), 51 (10.50). HRMS (EI) calcd. for C$_{13}$H$_{11}$OBr: 221.9993, found: 261.9991.
Compound 3f. 34 mg, yield: 64%; colorless oil. \(^1\)H NMR (CDCl\(_3\), 400 MHz, TMS) \(\delta\) 2.55-2.57 (m, 2H, CH\(_2\)), 2.78-2.80 (m, 2H, CH\(_2\)), 4.89 (dd, \(J_1 = 3.6\) Hz, \(J_2 = 2.0\) Hz, 2H, CH\(_2\)), 5.80 (dt, \(J_1 = 10.0\) Hz, \(J_2 = 3.6\) Hz, 1H, =CH), 6.32 (dt, \(J_1 = 10.0\) Hz, \(J_2 = 2.0\) Hz, 1H, =CH), 6.35 (s, 1H, =CH), 6.93 (d, \(J = 2.4\) Hz, 1H, Ar), 7.08 (d, \(J = 2.4\) Hz, 1H, Ar). \(^{13}\)C NMR (CDCl\(_3\), 100 MHz, TMS) \(\delta\) 27.5, 29.8, 65.5, 112.8, 122.8, 123.6, 123.8, 124.4, 127.8, 128.7, 133.7, 141.2, 151.3. IR (neat) \(v\) 2954, 2925, 2853, 1713, 1587, 1443, 1381, 1211, 1111, 1073, 995, 908, 883, 732, 637 cm\(^{-1}\). MS (%) m/e 262 (M\(^+\), 44.32), 183 (100.00), 155 (89.61), 128 (53.10), 115 (46.63), 102 (19.59), 91 (22.32), 77 (38.56), 51 (33.08). HRMS (EI) calcd. for C\(_{13}\)H\(_{11}\)OBr: 261.9993, found: 291.9990.
Compound $\mathbf{1g}$. 1.208 g, yield: 43%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 1.15-1.19 (m, 2H, CH$_2$), 1.38-1.42 (m, 2H, CH$_2$), 4.95 (s, 2H, CH$_2$), 7.00 (dd, $J_1$ = 7.6 Hz, $J_2$ = 7.6 Hz, 1H, Ar), 7.08 (d, $J$ = 8.0 Hz, 1H, Ar), 7.09-7.20 (m, 2H, =CH, Ar), 7.28-7.31 (m, 3H, Ar), 7.43 (dd, $J_1$ = 7.6 Hz, $J_2$ = 2.4 Hz, 2H, Ar), 7.78 (d, $J$ = 7.6 Hz, 1H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 0.6, 3.9, 57.4, 84.2, 87.0, 112.1, 113.1, 121.5, 122.4, 124.6, 126.7, 127.6, 127.8, 128.2, 128.6, 131.8, 154.4. IR (neat) $\nu$ 3062, 2921, 2856, 2238, 1773, 1744, 1597, 1488, 1370, 1261, 1221, 1188, 1017, 908, 751 cm$^{-1}$. MS (%) m/e 260 (M$^+$, 100.00), 245 (9.54), 231 (17.09), 165 (8.76), 153 (10.29), 131 (33.01), 115 (17.35), 91 (9.03), 51 (5.37). HRMS (El) calcd. for $\text{C}_{19}\text{H}_{16}\text{O}$: 260.1021, found: 260.1023.
Compound 2g. 44 mg, yield: 83%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 1.16-1.20 (m, 2H, CH$_2$), 1.38-1.42 (m, 2H, CH$_2$), 4.88 (d, $J$ = 4.0 Hz, 2H, CH$_2$), 5.82 (t, $J$ = 4.0 Hz, 1H, =CH), 6.81-6.88 (m, 2H, Ar), 7.13 (s, 1H, =CH), 7.33-7.41 (m, 5H, Ar), 7.65 (d, $J$ = 7.2 Hz, 1H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 0.6, 3.9, 65.1, 111.8, 119.8, 120.6, 123.8, 124.3, 124.5, 126.1, 126.4, 127.7, 128.3, 128.6, 137.4, 138.4, 151.2. IR (neat) v 3051, 2973, 2918, 1837, 1777, 1634, 1589, 1493, 1460, 1354, 1259, 1186, 1020, 761 cm$^{-1}$. MS (%) m/e 260 (M$^+$, 100.00), 245 (29.69), 215 (31.71), 202 (29.46), 183 (20.39), 145 (30.79), 128 (18.41), 115 (49.74), 63 (8.44). HRMS (EI) calcd. for C$_{19}$H$_{16}$O: 260.1201, found: 260.1202.
Compound 3g. 40 mg, yield: 76%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 2.59 (br s, 2H, CH$_2$), 2.86-2.87 (m, 2H, CH$_2$), 4.89 (dd, $J_1 = 10.0$ Hz, $J_2 = 4.0$ Hz, 2H, CH2), 5.81 (t, $J = 4.0$ Hz, 1H, =CH), 6.38 (s, 1H, =CH), 6.78-6.82 (m, 1H, Ar), 6.88 (d, $J = 8.0$ Hz, 1H, Ar), 7.08 (d, $J = 8.0$ Hz, 1H, Ar), 7.31-7.33 (m, 2H, Ar), 7.35-7.38 (m, 3H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 27.5, 30.0, 65.0, 119.6, 120.4, 122.9, 123.6, 125.0, 126.5, 127.7, 128.3, 128.6, 132.2, 137.2, 138.5, 142.6, 153.1. IR (neat) v 3054, 2915, 2834, 1635, 1600, 1461, 1444, 1351, 1227, 1110, 1087, 956, 851, 754, 652 cm$^{-1}$. MS (%) m/e 260 (M$^+$, 100.00), 245 (30.35), 215 (19.29), 183 (9.42), 152 (9.75), 128 (8.36), 115 (23.76), 77 (8.27), 51 (4.61). HRMS (EI) calcd. for C$_{19}$H$_{16}$O: 260.1201, found: 260.1198.
Compound 1h. 448 mg, yield: 21%; white solid. MP: 72-75 °C. 

1H NMR (CDCl₃, 400 MHz, TMS) δ 1.14-1.17 (m, 2H, CH₂), 1.34-1.38 (m, 2H, CH₂), 2.54 (t, J = 2.4 Hz, 1H, CH), 4.70 (d, J = 2.4 Hz, 2H, CH₂), 6.94-6.97 (m, 2H, Ar), 7.05 (s, 1H, =CH), 7.66 (d, J = 8.0 Hz, 1H, Ar). 

13C NMR (CDCl₃, 100 MHz, TMS) δ 0.7, 3.9, 56.4, 76.0, 78.0, 111.1, 113.1, 121.7, 125.3, 126.3, 127.4, 132.5, 154.4. 

IR (neat) ν 3296, 2923, 2853, 2123, 1739, 1591, 1486, 1455, 1376, 1242, 1171, 1096, 1020, 931, 872 cm⁻¹. 

MS (%) m/e 218 (M⁺, 2.56), 183 (20.49), 179 (74.67), 155 (8.26), 144 (21.27), 115 (100.00), 89 (16.21), 75 (14.83), 51 (9.37). 

HRMS (EI) calcd. for C₁₃H₁₁OCl: 218.0498, found: 218.0506.
Compound 2h. 27 mg, yield: 61%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 1.14-1.18 (m, 2H, CH$_2$), 1.34-1.38 (m, 2H, CH$_2$), 4.82 (dd, $J_1 = 3.6$ Hz, $J_2 = 1.6$ Hz, 2H, CH$_2$), 5.91 (dt, $J_1 = 10.0$ Hz, $J_2 = 3.6$ Hz, 1H, =CH), 6.80 (d, $J = 10.0$ Hz, 1H, =CH), 6.88 (d, $J = 8.4$ Hz, 1H, Ar), 6.99 (s, 1H, =CH), 7.50 (d, $J = 8.4$ Hz, 1H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 0.6, 3.9, 65.2, 111.1, 120.4, 121.5, 121.7, 122.9, 124.7, 124.9, 126.3, 129.4, 151.3. IR (neat) $\nu$ 2974, 2839, 1777, 1574, 1466, 1434, 1428, 1325, 126.3, 129.4, 151.3. MS (%) m/e 218 (M$^+$, 12.96), 183 (100.00), 155 (14.02), 153 (27.29), 128 (15.48), 115 (17.10), 91 (7.33), 77 (11.47), 63 (9.38). HRMS (EI) calcd. for C$_{13}$H$_{11}$OCl: 218.0498, found: 2118.0501.
Compound 3h. 20 mg, yield: 46%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 2.55-2.56 (m, 2H, CH$_2$), 2.79-2.81 (m, 2H, CH$_2$), 4.86 (dd, $J_1 = 3.6$ Hz, $J_2 = 2.0$ Hz, 2H, CH$_2$), 5.89 (dt, $J_1 = 10.0$ Hz, $J_2 = 3.6$ Hz, 1H, =CH), 6.32 (s, 1H, =CH), 6.79 (d, $J = 10.0$ Hz, 1H, =CH), 6.86 (d, $J = 8.0$ Hz, 1H, Ar), 6.93 (d, $J = 8.0$ Hz, 1H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 27.5, 29.8, 65.1, 120.2, 121.2, 121.4, 121.5, 122.6, 126.3, 130.0, 132.4, 141.7, 153.2. IR (neat) $\nu$ 2920, 2850, 1707, 1673, 1578, 1464, 1426, 1359, 1218, 1149, 1047, 959, 847, 847, 810, 730 cm$^{-1}$. MS (%) m/e 218 (M$^+$, 1.90), 183 (15.13), 179 (58.47), 155 (6.15), 144 (17.03), 115 (100.00), 89 (15.73), 75 (13.85), 51 (7.83). HRMS (EI) calcd. for C$_{13}$H$_{11}$OCl: 218.0498, found: 218.0501.
Compound 1i. 290 mg, yield: 29%; yellow solid. MP: 112-114 °C. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 1.21-1.25 (m, 2H, CH$_2$), 1.47-1.52 (m, 2H, CH$_2$), 2.59 (t, $J = 2.4$ Hz, 1H, CH), 4.85 (d, $J = 2.4$ Hz, 2H, CH$_2$), 7.06 (d, $J = 9.2$ Hz, 1H, Ar), 7.09 (t, $J = 2.0$ Hz, 1H, =CH), 8.09 (dd, $J_1 = 9.2$ Hz, $J_2 = 2.8$ Hz, 1H, Ar), 8.60 (d, $J = 2.8$ Hz, 1H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 0.8, 3.9, 56.5, 76.6, 77.2, 110.4, 111.8, 122.1, 123.2, 128.4, 128.5, 142.2, 158.3. IR (neat) $\nu$ 3285, 3106, 22919, 2135, 1735, 1610, 1578, 1505, 1484, 1335, 1249, 1147, 938, 831, 746 cm$^{-1}$. MS (%) m/e 229 (M$^+$, 2.66), 212 (7.70), 190 (29.43), 168 (14.62), 155 (6.62), 144 (32.23), 115 (100.00), 89 (20.81), 77 (11.05). HRMS (EI) calcd. for C$_{13}$H$_{11}$O$_3$N: 229.0739, found: 229.0736.
Compound 1j. 851 mg, yield: 43%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 1.11-1.15 (m, 2H, CH$_2$), 1.32-1.36 (m, 2H, CH$_2$), 2.51 (t, $J = 2.0$ Hz, 1H, CH), 3.79 (s, 1H, CH$_3$), 4.69 (d, $J = 2.0$ Hz, 2H, CH$_2$), 6.52-6.57 (m, 2H, Ar), 7.04 (s, 1H, =CH), 7.67 (d, $J = 8.4$ Hz, 1H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 0.6, 3.8, 55.4, 56.4, 75.5, 78.6, 100.0, 106.2, 111.5, 120.8, 122.1, 127.4, 155.1, 159.4. IR (neat) $\nu$ 3287, 2995, 2970 2836, 2121, 1781, 1607, 1503, 1444, 1256, 1160, 1027, 974, 827, 763 cm$^{-1}$. MS (%) m/e 214 (M$^+$, 10.24), 183 (3.96), 175 (100.00), 159 (17.78), 147 (20.52), 132 (20.63), 115 (60.94), 103 (24.14), 77 (26.11). HRMS (EI) calcd. for C$_{14}$H$_{14}$O$_2$: 214.0994, found: 214.0985.
Compound 1k. 103 mg, yield: 22%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 1.15-1.19 (m, 2H, CH$_2$), 1.29 (t, $J = 6.8$ Hz, 3H, CH$_3$), 1.37-1.41 (m, 2H, CH$_2$), 4.20-4.25 (m, 2H, CH$_2$), 4.82 (s, 2H, CH$_2$), 6.93 (d, $J = 8.4$ Hz, 2H, Ar), 7.00 (dd, $J_1 = 7.6$ Hz, $J_2 = 7.6$ Hz, 1H, Ar), 7.12 (s, 1H, =CH), 7.19 (dd, $J_1 = 7.6$ Hz, $J_2 = 7.6$ Hz, 1H, Ar), 7.77 (d, $J = 7.6$ Hz, 1H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 0.6, 3.9, 13.9, 56.0, 62.2, 78.5, 81.8, 111.7, 112.6, 122.0, 125.0, 126.8, 127.6, 127.8, 152.9, 153.8. IR (neat) $\nu$ 2977, 2920, 2866, 2242, 1713, 1598, 1489, 1366, 1247, 1115, 1072, 1021, 976, 802, 749 cm$^{-1}$. MS (%) m/e 256 (M$^+$, 37.51), 211 (10.64), 183 (100.00), 165 25.66), 153 (27.24), 128 (23.99), 115 (39.30), 91 (12.72), 77 (18.08). HRMS (EI) calcd. for C$_{16}$H$_{16}$O$_3$: 256.1099, found: 256.1102.
Compound 11. 560 mg, yield: 92%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 2.04-2.12 (m, 2H, CH$_2$), 2.49 (t, $J$ = 2.4 Hz, 1H, CH), 2.86-2.90 (m, 2H, CH$_2$), 2.96-3.01 (m, 2H, CH$_2$), 4.69 (d, $J$ = 2.4 Hz, 2H, CH$_2$), 6.42 (t, $J$ = 2.4 Hz, 1H, =CH), 6.93-6.97 (m, 2H, Ar), 7.11-7.16 (m, 1H, Ar), 7.24 (d, $J$ = 8.0 Hz, 1H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 18.3, 32.6, 32.8, 56.2, 75.3, 78.8, 112.4, 114.5, 121.3, 126.7, 127.4, 127.7, 145.0, 153.9. IR (neat) $\nu$ 3289, 2952, 2912, 2122, 1739, 1671, 1597, 1486, 1261, 1116, 1024, 925, 871, 747 cm$^{-1}$. MS (%) m/e 198 (M$^+$, 31.67), 183 (11.04), 159 (42.34), 143 (16.52), 131 (100.00), 115 (32.69), 91 (34.47), 77 (46.65), 51 (15.03). HRMS (EI) calcd. for C$_{14}$H$_{14}$O: 198.1045, found: 198.1039.
Compound 21. 13 mg, yield: 33%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) 2.04-2.12 (m, 2H, CH$_2$), 2.88 (t, $J = 7.6$ Hz, 2H, CH), 2.98 (t, $J = 7.6$ Hz, 2H, CH), 4.83 (dd, $J_1 = 3.6$ Hz, $J_2 = 2.0$ Hz, 2H, CH$_2$), 5.77 (dt, $J_1 = 10.0$ Hz, $J_2 = 3.6$ Hz, 1H, =CH), 6.33 (t, $J = 2.4$ Hz, 1H, =CH), 6.40 (d, $J = 10.0$ Hz, 1H, =CH), 6.78-6.82 (m, 2H, Ar), 7.07 (dd, $J_1 = 6.4$ Hz, $J_2 = 2.4$ Hz, 1H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) 18.2, 32.6, 32.7, 65.5, 114.1, 120.6, 121.7, 122.3, 124.4, 124.9, 125.4, 127.3, 144.9, 150.3. IR (neat) 3050, 2952, 2924, 2852, 1671, 1639, 1460, 1441, 1260, 1234, 1083, 1028, 953, 849, 747, 692 cm$^{-1}$. MS (m/e 198 (M$^+$, 100.00), 183 (31.33), 169 (68.07), 155 (32.41), 141 (64.35), 128 (30.11), 115 (73.21), 91 (16.72), 51 (1.95). HRMS (EI) calcd. for C$_{14}$H$_{14}$O: 198.1045, found: 198.1042.
Compound 1m. 986 mg, yield: 36%; colorless oil. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) $\delta$ 2.04-2.12 (m, 2H, CH$_2$), 2.86-2.91 (m, 2H, CH$_2$), 2.97-3.03 (m, 2H, CH$_2$), 4.91 (s, 2H, CH$_2$), 6.47 (t, $J = 2.4$ Hz, 1H, =CH), 6.93-6.97 (m, 1H, Ar), 7.04-7.06 (m, 1H, Ar), 7.13-7.17 (m, 1H, Ar), 7.25-7.30 (m, 4H, Ar), 7.42-7.44 (m, 2H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) $\delta$ 18.3, 32.7, 32.8, 57.2, 84.2, 87.0, 112.7, 114.6, 121.2, 122.4, 126.8, 127.4, 127.6, 128.2, 128.6, 131.8, 144.9, 154.2. IR (neat) $\nu$ 3056, 2950, 2856, 2238, 1671, 1596, 1485, 1453, 1373, 1216, 1030, 999, 871, 747 cm$^{-1}$. MS (%) m/e 274 (M$^+$, 12.90), 245 (12.83), 215 (3.26), 183 (3.84), 159 (7.38), 131 (28.09), 115 (100.00), 91 (9.27), 77 (11.33). HRMS (EI) calcd. for C$_{20}$H$_{18}$O: 274.1358, found: 274.1345.
Compound 2m. 44 mg, yield: 80%; white solid. MP: 95-97 °C. $^1$H NMR (CDCl$_3$, 400 MHz, TMS) 2.05-2.13 (m, 2H, CH$_2$), 2.90 (t, $J = 7.6$ Hz, 2H, CH), 3.00 (t, $J = 7.6$ Hz, 2H, CH), 4.84 (d, $J = 4.0$ Hz, 2H, CH$_2$), 5.79 (t, $J = 4.0$ Hz, 1H, =CH), 6.41 (s, 1H, =CH), 6.77-6.83 (m, 2H, Ar), 7.13 (d, $J = 6.8$ Hz, 1H, Ar), 7.32-7.39 (m, 5H, Ar). $^{13}$C NMR (CDCl$_3$, 100 MHz, TMS) 18.3, 32.7, 32.8, 65.1, 114.3, 119.7, 120.4, 123.7, 125.9, 127.4, 127.7, 128.3, 128.6, 137.5, 138.5, 145.0, 151.0. IR (neat) 3059, 2951, 2901, 2829, 1671, 1586, 1458, 1438, 1293, 1220, 1187, 1096, 907, 810, 731 cm$^{-1}$. MS (%) m/e 274 (M$,^+$, 100.00), 245 (26.06), 215 (14.24), 189 (7.13), 165 (5.14), 131 (7.42), 115 (19.49), 91 (5.71), 77 (3.68). HRMS (EI) calcd. for C$_{20}$H$_{18}$O: 274.1358, found: 274.1352.
7. References

