Supporting information

Tin-free radical reactions under minimal solvent conditions for the synthesis of substituted chromones and coumarins

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**General Methods:** All chromones, coumarins, Lewis acids, alkyl iodides, triethylborane, and solvents (dichloromethane and tetrahydrofuran) were purchased from Aldrich chemicals and used without further purification.

\(^1\)H-NMR were recorded on a Varian Gemini 200 MHz instrument. Chemical shifts are reported in parts per million (ppm) down field from TMS, using residual CDCl\(_3\) (7.27 ppm) as an internal standard. Data are reported as follows: Chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, dd = doublet of doublet, bs = broad singlet), coupling constant and integration. \(^{13}\)C-NMR was recorded on a Varian Gemini 200 MHz (50 MHz) instrument using broadband proton decoupling. Chemical shifts are reported in parts per million (ppm) downfield from TMS, using the middle resonance of CDCl\(_3\) (77.0) as an internal standard. Infrared spectra were recorded on Thermofisher IR100 FTIR instrument using NaCl pellets. Absorptions are given in wavenumbers (cm\(^{-1}\)).

**2-isopropylchroman-4-one (2a):** 95% yield; IR (cm\(^{-1}\)) 2964, 2876, 1691, 1605, 1577, 1463, 1304, 1229, 1115; \(^1\)H NMR (CDCl\(_3\), 200 MHz) \(\delta\) 7.87 (dd, \(J = 1.8, 4.2\) Hz, 1H), 7.52-7.42 (m, 1H), 7.04-6.94 (m, 2H), 4.26-4.11 (m, 1H), 2.70 (d, \(J = 7.2\) Hz, 1H), 1.06 (d, \(J = 6.8\) Hz, 3H), 1.07 (d, \(J = 6.8\) Hz, 3H); \(^{13}\)C NMR (CDCl\(_3\), 50 MHz) \(\delta\) 193.4, 162.1, 136.2, 127.1, 121.3, 121.2, 118.1, 82.7, 40.3, 32.4, 18.1; (CI/MS) \(m/z\) Calcd for C\(_{12}\)H\(_{15}\)O\(_2\) [M+H]: 191.1; found: 191.0.

**2-(tert-butyl)chroman-4-one (2b):** 97% yield, Known compound. \(^1\)H NMR, \(^{13}\)C NMR and HRMS are consistent with literature value.\(^1\)

2-cyclohexylchroman-4-one (2c): 85% yield; IR (cm\(^{-1}\)) 2927, 2853, 1692, 1607, 1577, 1463, 1306, 1228, 1148; \(^1\)H NMR (CDCl\(_3\), 200 MHz) \(\delta\) 7.90-7.83 (m, 1H), 7.51-7.41 (m, 1H), 7.05-6.93 (m, 2H), 4.26-4.12 (m, 1H), 2.77-2.64 (m, 2H), 1.99 (d, \(J = 10.4\) Hz, 1H), 1.98-1.62 (m, 5H), 1.42-0.96 (m, 5H); \(^{13}\)C NMR (CDCl\(_3\), 50 MHz) \(\delta\) 193.4, 162.1, 136.1, 127.1, 121.2, 118.1, 82.2, 42.0, 40.5, 28.5, 28.4, 26.5, 26.2, 26.1; (CI/MS) m/z Calcd for C\(_{15}\)H\(_{19}\)O\(_2\) [M+H]: 231.1; found: 231.1.

2-cyclopentylchroman-4-one (2d): 82% yield; IR (cm\(^{-1}\)) 2953, 2868, 1691, 1607, 1576, 1463, 1304, 1228, 1147; \(^1\)H NMR (CDCl\(_3\), 200 MHz) \(\delta\) 7.91-7.82 (m, 1H), 7.52-7.40 (m, 1H), 7.04-6.92 (m, 2H), 4.29-4.14 (m, 1H), 2.74-2.67 (m, 2H), 2.30-2.15 (m, 1H), 2.03-1.45 (m, 6H), 1.43-1.20 (m, 2H); \(^{13}\)C NMR (CDCl\(_3\), 50 MHz) \(\delta\) 193.1, 162., 136.2, 127.1, 121.3, 118.2, 81.9, 44.3, 42.4, 29.0, 28.6, 25.8, 25.6; (CI/MS) m/z Calcd for C\(_{14}\)H\(_{17}\)O\(_2\) [M + Na]: 217.1; found: 217.1.

2-ethylchroman-4-one (2e): 80% yield; Known compound. \(^1\)H NMR, \(^{13}\)C NMR and MS are consistent with literature value.\(^2\)

2-isopropyl-4-oxochroman-3-carbonitrile (4a): 98% yield; 2:1 inseparable mixture of diastereomers, IR (cm\(^{-1}\)) 2968, 2879, 1702, 1606, 1579, 1464, 1307, 1228, 1150; \(^1\)H NMR (CDCl\(_3\), 200 MHz) \(\delta\) major diastereomer: 7.94-7.86 (m, 1H), 7.63-7.51 (m, 1H), 7.15-7.99 (m, 2H), 4.48-4.39 (dd, \(J = 2.5, 12.1\) Hz, 1H), 3.93 (d, \(J = 12.1\) Hz, 1H), 2.48-2.23 (m, 1H), 1.23 (d, \(J = 6.8\) Hz, 3H), 1.14 (d, \(J = 6.8\) Hz, 3H); minor diastereomer: 7.94-7.86 (m, 1H), 7.63-7.51 (m, 1H), 7.15-7.99 (m, 2H), 4.03-3.99 (dd, \(J = 2.5, 12.1\) Hz, 1H), 3.71 (d, \(J = 12.1\) Hz, 1H), 2.48-2.23 (m, 1H), 1.24 (d, \(J = 6.8\) Hz, 3H), 1.20 (d, \(J = 6.8\) Hz, 3H), 1.14 (d, \(J = 6.8\) Hz, 3H).

2-(tert-butyl)-4-oxochroman-3-carbonitrile (4b): 97% yield; 2:1 inseparable mixture of diastereomers, IR (cm\(^{-1}\)) 2968, 2879, 1702, 1606, 1579, 1464, 1307, 1228, 1150; \(^1\)H NMR (CDCl\(_3\), 200 MHz) \(\delta\) major diastereomer: 7.90 (d, \(J = 7.4\) Hz, 1H), 7.63-7.49 (m, 1H), 7.12-6.95 (m, 2H), 4.26 (dd, \(J = 1.0, 10.5\) Hz, 1H), 3.87 (dd, \(J = 1.0, 10.5\) Hz, 1H), 1.23 (s, 9H); minor diastereomer: 7.90 (d, \(J = 7.4\) Hz, 1H), 7.63-7.49 (m, 1H), 7.12-6.95 (m, 2H), 3.97 (dd, \(J = 1.0, 2.0\) Hz, 1H), 3.63 (dd, \(J = 1.0, 2.0\) Hz, 1H), 1.21 (s, 9H); \(^13\)C NMR (CDCl\(_3\), 50 MHz) \(\delta\) 183.7, 183.3, 162.0, 161.3, 137.6, 137.5, 128.6, 127.9, 122.7, 118.8, 118.5, 118.4, 118.2, 114.9, 114.2, 85.7, 85.1, 45.8, 39.1, 36.1, 35.4, 26.4, 26.3, 25.6; HRMS Exact mass calcd for C\(_{14}\)H\(_{15}\)NO\(_2\)Na [M + Na]": 252.1000; Found: 252.0993.

2-cyclohexyl-4-oxochroman-3-carbonitrile (4c): 94% yield; 1.3:1 inseparable mixture of diastereomers; The reaction was done following the general procedure listed in the paper. Additionally, the silica bed was first washed with 15 mL hexane to remove non-volatile cyclohexyl iodide followed by ether; IR (cm\(^{-1}\)) 2930, 2855, 1703, 1607, 1579, 1465, 1307, 1227, 1148; \(^1\)H NMR (CDCl\(_3\), 200 MHz) \(\delta\) major diasteromer: 7.94-7.86 (m, 1H), 7.62-7.50 (m, 1H), 7.14-6.99 (m, 2H), 4.41 (dd, \(J = 2.3, 11.9\) Hz, 1H), 3.98 (d, \(J = 11.9\) Hz, 1H), 2.43-2.26 (m, 1H), 2.21-1.58 (m, 6H), 1.56-0.90 (m, 4H); minor diastereomer: 7.94-7.86 (m, 1H), 7.62-7.50 (m, 1H), 7.14-6.99 (m, 2H), 4.06 (dd, \(J = 2.7, 9.4\) Hz, 1H), 3.96 (d, \(J = 2.5\) Hz, 1H), 2.43-2.26 (m, 1H), 2.21-1.58 (m, 6H), 1.56-0.90 (m, 4H); \(^13\)C NMR (CDCl\(_3\), 50 MHz) \(\delta\) 183.8, 182.9, 161.6, 161.2, 137.7, 137.5, 128.3, 128.0, 122.7, 122.6, 119.1, 118.8, 118.5, 118.3, 113.8, 113.3, 82.3, 82.2,
2-cyclopentyl-4-oxochroman-3-carbonitrile (4d): 96% yield; 1.1:1 inseparable mixture of diastereomers; the reaction was done following the general procedure listed in the paper. Additionally, the silica bed was first washed with 15 mL hexane to remove non-volatile cyclopentyl iodide followed by ether; IR (cm\(^{-1}\)) 2954, 2870, 1702, 1607, 1578, 1464, 1306, 1226, 1148; \(^1\)H NMR (CDCl\(_3\), 200 MHz) \(\delta\) major diasteromer: 7.93-7.86 (m, 1H), 7.63-7.50 (m, 1H), 7.14-6.98 (m, 2H), 4.58 (dd, \(J = 3.9, 11.4\) Hz, 1H), 3.87 (d, \(J = 11.5\) Hz, 1H), 2.69-2.45 (m, 1H), 2.21-1.77 (m, 4H), 1.75-1.44 (m, 4H); minor diasteromer: 7.93-7.86 (m, 1H), 7.63-7.50 (m, 1H), 7.14-6.98 (m, 2H), 4.15-4.07 (m, 1H), 3.66 (d, \(J = 2.5\) Hz, 1H), 2.69-2.45 (m, 1H), 2.21-1.77 (m, 4H), 1.75-1.44 (m, 4H); \(^{13}\)C NMR (CDCl\(_3\), 50 MHz) \(\delta\) 183.4, 182.8, 161.5, 161.1, 137.7, 137.5, 128.3, 128.0, 122.7, 122.6, 119.1, 118.9, 118.5, 118.4, 114.0, 113.4, 82.4, 80.6, 44.6, 42.5, 42.4, 42.3, 30.0, 28.6, 26.0, 26.0, 25.9, 25.5, 25.4; m/z Calcd for C\(_{16}\)H\(_{18}\)NO\(_2\) [M+H]: 256.1; found: 256.2.

2-ethyl-4-oxochroman-3-carbonitrile (4e): 87% yield; 2:1 inseparable mixture of diastereomers, IR (cm\(^{-1}\)) 2973, 2937, 2882, 1701, 1607, 1578, 1464, 1310, 1226, 1150, 1120; \(^1\)H NMR (CDCl\(_3\), 200 MHz) \(\delta\) major diasteromer: 7.97-7.84 (m, 1H), 7.66-7.51 (m, 1H), 7.16-6.96 (m, 2H), 4.57-4.35 (m, 1H), 3.85 (d, \(J = 12.1\) Hz, 1H), 2.29-1.79 (m, 2H), 1.19 (t, \(J = 7.2\) Hz, 3H); minor diasteromer: 7.97-7.84 (m, 1H), 7.66-7.51 (m, 1H), 7.16-6.96 (m, 2H), 4.57-4.35 (m, 1H), 3.74 (d, \(J = 3.1\) Hz, 1H), 2.29-1.79 (m, 2H), 1.13 (t, \(J = 7.6\) Hz, 3H); \(^{13}\)C NMR (CDCl\(_3\), 50 MHz) \(\delta\) 183.3, 182.5, 161.1, 160.9, 137.8, 137.5, 128.2, 128.0, 122.7, 119.1, 119.0, 118.6, 118.3, 113.8, 113.3, 79.5, 79.1, 44.7, 43.0, 27.0, 25.4, 9.7, 8.9; (CI/MS) m/z Calcd for C\(_{13}\)H\(_{12}\)NO\(_2\) [M+H]: 202.1; found: 202.0.
4-isopropyl-2-oxochroman-3-carbonitrile (6a): 94% yield; 2.3:1 inseparable mixture of diastereomers, IR (cm\(^{-1}\)) 2967, 2879, 1766, 1614, 1588, 1488, 1456, 1367, 1239, 1213, 1164, 1118, 762; \(^1\)H NMR (CDCl\(_3\), 200 MHz) \(\delta\) major diastereomer: 7.41-7.07 (m, 4H), 4.09 (d, \(J = 6.3\) Hz, 1H), 3.32-3.27 (dd, \(J = 3.9, 6.3\) Hz, 1H), 2.95-2.34 (m, 1H), 1.06 (d, \(J = 7.0\) Hz, 3H); minor diastereomer: 7.41-7.07 (m, 4H), 4.02 (d, \(J = 2.0\) Hz, 1H), 3.03-2.98 (dd, \(J = 2.0, 8.2\) Hz, 1H), 1.87-1.69 (m, 1H), 1.01 (d, \(J = 6.6\) Hz, 3H), 0.77 (d, \(J = 6.6\) Hz, 3H); \(^{13}\)C NMR (CDCl\(_3\), 50 MHz) \(\delta\) 162.2, 160.2, 151.2, 150.6, 130.3, 130.0, 129.9, 125.6, 125.2, 121.8, 120.3, 117.6, 117.6, 114.2, 47.6, 44.6, 38.3, 25.4, 32.0, 30.8, 21.7, 20.3, 19.8, 16.7; (CI/MS) \(m/z\) Calcd for C\(_{13}\)H\(_{14}\)NO\(_2\) [M+H]: 216.1; found: 216.1.

4-tert-butyl-2-oxochroman-3-carbonitrile (6b): 96% yield; 1.6:1 IR (cm\(^{-1}\)) 2964, 2871, 1755, 1615, 1487, 1457, 1371, 1349, 1280, 1255, 1221, 1171, 1112, 1046, 908; \(^1\)H NMR (CDCl\(_3\), 200 MHz) \(\delta\) major diastereomer: 7.43-7.13 (m, 4H), 4.18 (d, \(J = 5.5\) Hz, 1H), 3.22 (d, \(J = 5.5\) Hz, 1H), 1.10 (s, 9H); minor diastereomer: 7.43-7.13 (m, 4H), 3.74-3.77 (m, 1H), 3.05 (s, 1H), 0.97 (s, 9H); \(^{13}\)C NMR (CDCl\(_3\), 50 MHz) \(\delta\) 160.8, 151.1, 131.6, 130.1, 126.3, 119.8, 117.7, 114.8, 51.5, 35.2, 34.0, 28.6, 27.3; (CI/MS) \(m/z\) Calcd for C\(_{14}\)H\(_{16}\)NO\(_2\) [M+H]: 230.1; found: 230.0.

4-cyclohexyl-2-oxochroman-3-carbonitrile (6c): 81% yield; 2.7:1 inseparable mixture of diastereomers; The reaction was done following the general procedure listed in the paper. Additionally, the silica bed was first washed with 15 mL hexane to remove non-volatile cyclohexyl iodide followed by ether; IR (cm\(^{-1}\)) 2929, 2855, 1770, 1487, 1455, 1360, 1225, 1161, 1115, 1002, 762; \(^1\)H NMR (CDCl\(_3\)) \(\delta\) major diastereomer: 7.42-7.08 (m, 4H), 4.06 (d, \(J = 7.4\) Hz, 1H), 3.29-3.23 (dd, \(J = 3.9, 6.3\) Hz,
1H), 3.05-3.00 (dd, \(J = 2.0, 8.2\) Hz, 1H), 2.12-0.63 (m, 11H); minor diastereomer: 7.42-7.08 (m, 4H), 4.06 (d, \(J = 7.4\) Hz, 1H), 3.05-3.00 (dd, \(J = 2.0, 8.2\) Hz, 1H), 2.12-0.63 (m, 11H);

\[ ^{13}\text{C NMR (CDCl}_3, 50\text{ MHz}) \delta 162.3, 160.2, 151.1, 150.6, 130.3, 129.9, 129.8, 129.8, 121.8, 121.2, 117.6, 117.5, 114.6, 114.2, 46.9, 44.6, 41.1, 40.5, 38.0, 35.1, 31.6, 30.6, 30.1, 27.2, 26.4, 26.1, 26.0, 25.9, 25.8; \text{(CI/MS) } m/z \text{ Calcd for } \text{C}_{16}\text{H}_{18}\text{NO}_2 [\text{M+H}]: 256.1; \text{found: 256.0.} \]

4-cyclopentyl-2-oxochroman-3-carbonitrile (6d): 83% yield; 1.8:1 inseparable mixture of diasteromers; The reaction was done following the general procedure listed in the paper. Additionally, the silica bed was first washed with 15 mL hexane to remove non-volatile cyclopentyl iodide followed by ether; IR (cm\(^{-1}\)) 2957, 2872, 1778, 1614, 1588, 1487, 1456, 1350, 1238, 1214, 1163, 1110, 1013, 911, 762; \(^1\text{H NMR (CDCl}_3, 200\text{ MHz}) \delta \text{ major diasteromer: 7.38-7.07 (m, 4H), 4.08 (d, } J = 5.5\text{ Hz, 1H), 3.43-3.37 (t, } J = 5.9\text{ Hz, 1H), 2.38-0.86 (m, 9H); minor diastereomer: 7.38-7.07 (m, 4H), 3.97 (d, } J = 1.6\text{ Hz, 1H), 3.09-3.04 (dd, } J = 1.6, 9.4\text{ Hz, 1H), 2.38-0.86 (m, 9H); }^{13}\text{C NMR (CDCl}_3, 50\text{ MHz}) \delta 162.0, 160.0, 150.9, 150.4, 129.8, 129.8, 129.7, 129.6, 125.6, 125.3, 122.8, 122.5, 117.6, 117.6, 46.3, 43.8, 42.7, 42.7, 39.1, 36, 9, 31.2, 30.9, 30.6, 28.5, 24.9, 24.8, 24.4, 24.2; \text{(CI/MS) } m/z \text{ Calcd for } \text{C}_{15}\text{H}_{16}\text{NO}_2 [\text{M+H}]: 242.1; \text{found: 242.0.} \]

4-ethyl-2-oxochroman-3-carbonitrile (6e): 91% yield; 3:1 inseparable mixture of diasteromers, IR (cm\(^{-1}\)) 2970, 2936, 1770, 1613, 1588, 1487, 1455, 1360, 1204, 1163, 1119, 1020, 761; \(^1\text{H NMR (CDCl}_3) \delta \text{ major diastereomer: 7.40-6.93 (m, 4H), 3.99 (d, } J = 5.5\text{ Hz, 1H), 3.22-3.10 (m, 1H), 2.10-1.92 (m, 2H), 0.91 (t, } J = 7.4\text{ Hz, 3H); minor diastereomer: 7.40-6.93 (m, 4H), 3.77 (d, } J = 4.6\text{ Hz, 1H), 3.31-3.17 (m, 1H), 2.10-1.92 (m, 2H), 0.93 (t, } J = 7.4\text{ Hz, 3H); }^{13}\text{C NMR (CDCl}_3, 50\text{ MHz}) \delta 150.4, 129.9, 129.8, 129.6, 128.9, 128.4, 127.0, 125.8, 125.5, 125.4, 123.4, 118.1, 117.8, 42.2, 40.8, 39.3,
37.2, 30.9, 26.0, 25.3, 24.9, 11.1; (CI/MS) m/z Calcd for C_{12}H_{12}NO_{2} [M+H]: 202.1.1; found: 202.1.
200 MHz, $^1$H NMR
200 MHz, $^1$H NMR

Electronic Supplementary Material (ESI) for Green Chemistry
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200 MHz, $^{13}\text{C}$ NMR

2c
200 MHz, $^1$H NMR

![Chemical structure of 2d](image)
200 MHz, $^{13}$C NMR

2d
200 MHz, $^1$H NMR

Electronic Supplementary Material (ESI) for Green Chemistry
This journal is © The Royal Society of Chemistry 2011
Sample directory: 87A_18May2011
File: CARBON

Pulse Sequence: s2pul
Date: May 18 2011
Solvent: CDC13
Ambient temperature
Mercury-200 "chemsunn"

Relax. delay 2.000 sec
Pulse 45.0 degrees
Acq. time 1.49s sec
Width 12578.6 Hz
1884 repetitions
OBSERVE C13, 50.2832616 MHz
DECOUPLE H1, 198.9740455 MHz
Power 32 dB
continuously on
WALTZ-16 modulated
DATA PROCESSING
Line broadening 1.0 Hz
FT size 65536
Total time 4 hr, 57 min, 30 sec
200 MHz, $^1$H NMR
200 MHz, $^{13}$C NMR

![Chemical structure of 4b]

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200 MHz, $^1\text{H}$ NMR

Electronic Supplementary Material (ESI) for Green Chemistry
This journal is © The Royal Society of Chemistry 2011
Pulse Sequence: s2pul
Date: May 18 2011
Solvent: CDCl3
Ambient temperature: 25°C
H: Chemsun
Relax, delay 2.000 sec
Pulse 45.0 degrees
Acq. Time 1.456 sec
Width 12578.6 Hz
3520 repetitions
OBSERVE C13, 50.2832818 MHz
DECOUPLE H1, 199.8740855 MHz
Power 32 dB
continuously on
WALTZ-16 modulated
DATA PROCESSING
Line broadening 1.0 Hz
FI size 65536
Total time 4 hr, 57 min, 30 sec
200 MHz, $^1$H NMR

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200 MHz, $^{13}$C NMR

$\text{4d}$
200 MHz, $^1$H NMR

$^1$H NMR spectrum of compound 4e.
Archive directory: /export/home/jzine/vnmrsys/data
Sample directory: 87dcarb_19May2011
File: CARBON

Pulse Sequence: s2pul
Date: May 19 2011
Solvent: CDCl3
Ambient temperature
Mercury-200 "chemsun"

Relax. delay 2.000 sec
Pulse 45.0 degrees
Acq. time 1.498 sec
Width 12578.6 Hz
3336 repetitions

OBSERVE C13, 50.2832618 MHz
DECOUPLE H1, 139.9740055 MHz
Power 32 dB
Continuously on
WALTZ-16 modulated

DATA PROCESSING
Line broadening 1.0 Hz
FT size 65536
Total time 4 hr, 57 min, 30 sec
200 MHz $^1$H NMR
6a
200 MHz $^{13}$C NMR
200 MHz $^1$H NMR
200 MHz $^{13}$C NMR
$6c$

200 MHz $^1$H NMR
Electronic Supplementary Material (ESI) for Green Chemistry
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6c

200 MHz $^{13}$C NMR
6d
200 MHz $^1$H NMR
6d
200 MHz $^{13}$C NMR
200 MHz $^1$H NMR

![Chemical Structure of 6e](image)

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200 MHz, $^{13}$C NMR

![Chemical structure](image_url)

$^6e$
Crude NMR of 1g scale reaction

200 MHz, $^1$H NMR

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