2*H*-Chromenes from Salicylaldehydes by a Catalytic Petasis Reaction

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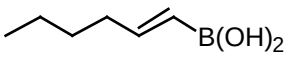
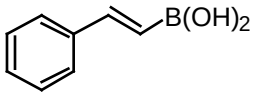
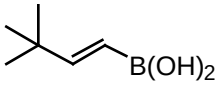
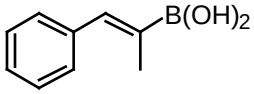
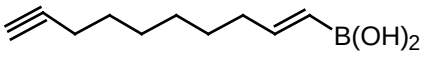
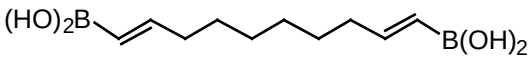
Supporting Information

1. Preparation of Alkenylboronic acids: performed by the procedure of Brown and coworkers.[1] ^{1}H NMR data is provided in Table S1.

Alkenylboronic acid	^{1}H NMR
 **3a**	6.84 (dt, J = 17.6, 6.3 Hz, 1 H), 5.50 (dt, J = 17.6, 1.2 Hz, 1 H), 2.18 (q, J = 6.6 Hz, 2 H), 1.5 - 1.2 (m, 4 H), 0.89 (t, J = 6.6 Hz, 3 H)
 **3b**	7.5 - 7.2 (m, 6 H), 6.36 (d, J = 18.2 Hz, 1 H)
 **3c**	6.56 (d, J = 18.1 Hz, 1 H), 5.42 (d, J = 18.1 Hz, 1 H), 1.03 (s, 9 H)
 **3d**	7.4 – 7.1 (m, 5 H), 7.09 (s, 0.5 H), 6.77 (s, 0.5 H), 1.90 (tt, J = 7.6, 1.7 Hz, 3 H)
 **3e**	6.53 (dt, J = 18.0, 6.3 Hz, 1 H), 5.56 (d, J = 17.5 Hz, 1 H), 2.2 – 2.1 (m, 3 H), 1.6 – 1.1 (m, 10 H)
 **3f**	6.53 (dt, J = 18.0, 6.3 Hz, 2 H), 5.56 (d, J = 17.5 Hz, 2 H), 2.2–2.1 (m, 4 H), 1.5 – 1.1 (m, 8 H)

2. Representative procedure for Petasis reaction: adapted from the literature method.[2]

N-(1-phenyl-1-(2-hydroxyphenyl)methyl)morpholine (**2a**): A mixture of morpholine (87 mg, 1 mmol), salicylaldehyde (122 mg, 1 mmol) and phenylboronic acid (122 mg, 1 mmol) was heated in dioxane (5 mL) at 90°C overnight. After cooling, water (20 mL) and dichloromethane (20 mL) were added. The aqueous layer was extracted with dichloromethane (10 mL) and the combined organic layer was washed with saturated aqueous sodium bicarbonate. Drying and concentration afforded the pure product as solid residue, 0.25 g (93%). ^{1}H-NMR ($CDCl_3$): δ 11.72 (s, broad, 1 H), 7.5 – 7.2 (m, 5 H), 7.12 (ddd, J = 9.0, 8.2, 1.6 Hz, 1 H), 6.94 (dd, J = 7.8, 1.6 Hz, 1 H), 6.86 (dd, J = 8.1, 1.6 Hz, 1 H), 6.72 (td, J = 7.4, 1.2 Hz, 1 H), 4.41 (s, 1 H), 3.8 – 3.6 (m, 4 H), 2.7 – 2.4 (m, 4 H). ^{13}C NMR ($CDCl_3$): δ 156.3, 139.5, 129.6, 129.2, 128.9, 128.7, 128.3, 125.0, 119.8, 117.3, 77.1, 67.2, 52.5. HRMS calcd for $C_{17}H_{19}NO_2$ ($[M–H]^+$): 268.1343; found: 268.1331.

N-(1-phenyl-1-(2,3-dihydroxyphenyl)methyl)morpholine (**2b**). Using the above procedure with 2,3-dihydroxylbenzaldehyde; 88% yield. ^{1}H-NMR: δ = 7.4 – 7.2 (m, 5 H), 6.8 (dd, J = 7.8, 1.6 Hz, 1 H), 6.64 (t, J = 7.8 Hz, 1 H), 6.49 (dd, J = 7.4, 1.6 Hz, 1 H), 4.43 (s, 1 H), 3.8 – 3.6 (m, 4 H), 2.7 – 2.4 (m, 4 H). ^{13}C-NMR: δ = 145.2, 143.3, 138.9, 129.8, 129.4, 129.1, 128.9, 128.5, 124.8, 120.5, 120.1, 115.5, 114.0, 76.6, 67.1, 52.4.

N-(1-phenyl-1-(2-hydroxy-3-methoxyphenyl)methyl)morpholine (**2c**). Using the above procedure with 2-hydroxy-3-methoxybenzaldehyde; 90% yield. ^{1}H-NMR: δ = 11.9 (br, 1 H), 7.5 – 7.2 (m, 5 H), 6.75 (dd, J = 7.8, 2.0 Hz, 1 H), 6.68 (t, J = 7.8 Hz, 1 H), 6.57 (dd, J = 7.0, 2.3 Hz, 1 H), 4.41 (s, 1 H), 3.87 (s, 3 H), 3.8 – 3.6 (m, 4 H), 2.7 – 2.4 (m, 4 H). ^{13}C-NMR: δ = 148.5, 145.6, 139.5, 129.1, 128.7, 128.3, 125.3, 121.3, 119.5, 110.6, 76.8, 67.2, 56.1, 52.5. HRMS calcd for $C_{18}H_{21}NO_3$ (MH^+): 300.1594; found: 300.1585.

3. Representative one-step solution-phase procedure for preparation of 2*H*-chromene.

*2-Butyl-2*H-*chromene* (**5a**): A solution of salicylaldehyde (61 mg, 0.5 mmol), (*E*)-1-hexenylboric acid (64 mg, 0.5 mmol) and dibenzylamine (5 mg, 0.025 mmol) in dioxane (2.5 mL) was stirred at 90°C overnight. After cooling to room temperature, water (10 mL) and dichloromethane (10 mL) were added. The aqueous layer was extracted with dichloromethane (10 mL) and the combined organic layers were washed with 10% hydrochloric acid and saturated aqueous sodium bicarbonate solution. Drying and concentration afforded the product as solid residue; 86 mg (92%). Further purification could be obtained by column chromatography over silica gel (hexanes:EtOAc 85:15). ^{1}H-NMR: δ = 7.09 (td, J = 7.6, 1.8 Hz, 1 H), 6.95 (dd, J = 7.6, 2.1 Hz, 1 H), 6.83 (td, J = 7.3, 1.2 Hz, 1 H), 6.77 (d, J = 7.9 Hz, 1 H), 6.38 (dd, J = 10.0, 1.8 Hz, 1 H), 5.68 (dd, J = 10.0, 3.5 Hz, 1 H), 4.84 (symm. m, 1 H), 1.8 – 1.2 (m, 6 H), 0.92 (t, J = 6.7 Hz, 3 H). ^{13}C-NMR: δ = 153.8, 129.3, 126.6, 126.2, 124.1, 122.3, 121.1, 116.2, 75.4, 35.4, 27.3, 27.3, 22.9, 14.3. HRMS calcd for $C_{13}H_{16}O$ ($[M^{\cdot+} - H^{\cdot}]^+$): 187.1128; found: 187.1122.

4. Representative two-step solution-phase procedure for preparation of 2*H*-chromene.

*2-Butyl-2*H-*chromene* (**5a**): Salicylaldehyde (122 mg, 1.0 mmol), (*E*)-1-hexenylboric acid (128 mg, 1.0 mmol) and morpholine (87 mg, 1.0 mmol) were heated in dioxane (5 mL) at 90 °C overnight. Upon cooling, water (10 mL) and dichloromethane (10 mL) were added. The aqueous layer was extracted with dichloromethane (10 mL) and the combined organic layer was washed with saturated aqueous sodium bicarbonate solution. Drying and concentration afforded a solid residue, which was revealed by NMR to be a mixture of *N-(1-(1-hexenyl)-1-(2-hydroxylphenyl) methyl)morpholine* **4** and **5a** (80:20 ratio). The mixture was refluxed in 2,6-lutidine (0.5 mL) for 30 min and then poured into 10% aqueous HCl. Extraction with dichloromethane, washing with saturated sodium hydrogencarbonate solution, drying and concentration gave **5a** as yellow solid; 120 mg (84%).

5. Preparation of polymer-bound dibenzylamine (**8**).[3] Merrifield resin (Advanced ChemTech, 100 – 200 mesh, 0.9 mmol/g, 2 g, 1.8 mmol) was pre-swollen with DMF (20 mL). After 30 min, benzylamine (1.0 g, 9.3 mmol) was added. The mixture was heated at 55 °C

overnight and then filtered. The resin was washed with DMF (4 × 20 mL) and dried under vacuum.

6. Representative procedure for preparation of 2*H*-chromene using solid-phase base 8.

*2-Butyl-2*H-*chromene* (**5a**): Dibenzylamino resin **8** (0.5 g, ca. 0.4 mmol) was pre-swollen in dioxane (5 mL) at room temperature for 15 min before addition of salicylaldehyde (61 mg, 0.5 mmol) and (*E*)-1-hexenylboric acid (64 mg, 0.5 mmol). The suspension was stirred vigorously at 90 °C overnight. Upon cooling, the resin was removed by filtration and the filtrate was passed through a thin layer of silica gel to remove the boric acid. Concentration gave the pure product as solid residue; 99%.

*2-Butyl-8-hydroxy-2*H-*chromene* (**5b**): As above, using 2,3-dihydoxybenzaldehyde and (*E*)-1-hexenylboric acid; 88%. ^{1}H-NMR: δ = 6.80 (dd, J = 7.4, 1.6 Hz, 1 H), 6.75 (t, J = 8.2 Hz, 1 H), 6.55 (dd, J = 6.6, 2.3 Hz, 1 H), 6.40 (dd, J = 9.8, 2.0 Hz, 1 H), 5.69 (dd, J = 9.8, 3.1 Hz, 1 H), 4.91 (symm. m, 1 H), 1.9 – 1.3 (m, 6 H), 0.93 (t, J= 6.6 Hz, 3 H). ^{13}C-NMR: δ = 144.4, 139.9, 126.1, 124.0, 122.2, 121.3, 118.1, 115.4, 76.1, 35.2, 27.4, 22.8, 14.3. HRMS calcd for $C_{13}H_{16}O_2$ ($[M^{\cdot+} - H^{\cdot}]^+$): 203.1077; found: 203.1070.

*2-Butyl-8-methoxy-2*H-*chromene* (**5c**): As above, using 2-hydoxy-3-methoxybenzaldehyde and (*E*)-1-hexenylboric acid; 91%. ^{1}H-NMR: δ = 6.8 – 6.7 (m, 2 H), 6.61 (dd, J = 5.6, 3.2 Hz, 1 H), 6.38 (dd, J = 10.0, 1.8 Hz, 1 H), 5.72 (dd, J = 10.0, 3.5 Hz, 1 H), 4.91 (symm. m, 1 H), 3.86 (s, 3 H), 1.9 – 1.3 (m, 6 H), 0.91 (t, J = 7.0 Hz, 3 H). ^{13}C-NMR: δ = 148.2, 142.6, 126.2, 124.0, 122.9, 120.6, 119.1, 112.5, 75.6, 56.4, 35.3, 27.2, 22.9, 14.3. HRMS calcd for $C_{14}H_{18}O_2$ ($[M^{\cdot+} - H^{\cdot}]^+$): 217.1234; found: 217.1227.

*2-Butyl-6-bromo-2*H-*chromene* (**5d**): As above, using 5-bromo-2-hydoxybenzaldehyde and (*E*)-1-hexenylboric acid; 90%. ^{1}H-NMR: δ = 7.16 (dd, J = 8.6, 2.3 Hz, 1 H), 7.05 (d, J = 2.3 Hz, 1 H), 6.64 (d, J = 8.6 Hz, 1 H), 6.30 (dd, J = 10.1, 1.2 Hz, 1 H), 5.71 (dd, J = 10.1, 3.5 Hz, 1 H), 4.82 (symm. m, 1 H), 1.8 – 1.3 (m, 6 H), 0.90 (t, J = 6.6 Hz, 3 H). ^{13}C-NMR: δ = 152.8, 131.7, 129.0, 127.4, 124.0, 123.1, 117.9, 113.0, 75.6, 35.3, 27.2, 22.8, 14.3.

*2-Butyl-6,8-dichloro-2*H-*chromene* (**5e**): As above, using 3,5-dichloro-2-hydoxybenzaldehyde and (*E*)-1-hexenylboric acid; 91%. ^{1}H-NMR: δ = 7.13 (d, J = 2.7 Hz, 1 H), 6.82 (d, J = 2.3 Hz, 1 H), 6.29 (dd, J = 10.2, 1.6 Hz, 1 H), 5.77 (dd, J = 10.2, 3.5 Hz, 1 H), 5.0 – 4.9 (m, 1 H), 1.8 – 1.2 (m, 6 H), 0.90 (t, J = 6.6 Hz, 3 H). ^{13}C-NMR: δ = 148.0, 129.1, 128.2, 125.5, 124.7, 124.3, 122.6, 121.9, 76.5, 35.3, 27.2, 22.7, 14.3.

*2-Butyl-6,8-di-tert-butyl-2*H-*chromene* (**5f**): As above, using 3,5-di-*tert*-butyl-2-hydoxybenzaldehyde and (*E*)-1-hexenylboric acid; 85%. ^{1}H-NMR: δ = 7.17 (d, J = 2.6 Hz, 1 H), 6.87 (d, J = 2.6 Hz, 1 H), 6.41 (dd, J = 9.7, 2.1 Hz, 1 H), 5.65 (dd, J = 9.7, 2.3 Hz, 1 H), 4.82 (symm. m, 1 H), 1.9 – 1.3 (m, 6 H), 1.40 (s, 9 H), 1.30 (s, 9 H), 0.95 (t, J = 7.0 Hz, 3 H). ^{13}C-NMR: δ = 150.3, 142.8, 136.6, 125.9, 125.7, 123.8, 122.3, 121.8, 74.8, 35.5, 34.9, 34.5, 31.8, 30.5, 27.7, 22.9, 14.3. HRMS calcd for $C_{21}H_{32}O$ ($[M^{\cdot+} - H^{\cdot}]^+$): 299.2369; found: 299.2376.

*2-Butyl-2*H-*benzo[e]chromene* (**5g**): As above, using 2-hydoxy-naphthaldehyde and (*E*)-1-hexenylboric acid; 93%. ^{1}H-NMR: δ = 7.95 (d, J = 8.5 Hz, 1 H), 7.75 (d, J = 8.2 Hz, 1 H), 7.66 (d, J = 8.8 Hz, 1 H), 7.49 (td, J = 6.7, 1.5 Hz, 1 H), 7.34 (td, J = 8.2, 1.2 Hz, 1 H), 7.10 (d, J = 10.0 Hz, 1 H), 7.09 (d, J = 8.5 Hz, 1 H), 5.82 (dd, J = 10.0, 3.5 Hz, 1 H), 4.93 (symm. m, 1 H), 2.0 – 1.3 (m, 6 H), 0.95 (t, J = 6.7 Hz, 3 H). ^{13}C-NMR: δ = 151.9, 130.2, 129.5, 129.4, 128.7, 126.7, 124.8, 123.7, 121.5, 120.3, 118.3, 115.0, 75.4, 34.8, 27.4, 22.9, 14.3. HRMS calcd for $C_{17}H_{18}O$ ($[M^{\cdot+} - H^{\cdot}]^{+}$): 237.1279; found: 237.1277.

*2-Phenyl-2*H-*chromene* (**5h**): As above, using salicylaldehyde and (*E*)-2-phenyl-1-ethenylboric acid; 96%. ^{1}H-NMR: δ = 7.5 – 7.3 (m, 5 H), 7.11 (td, J = 7.6, 1.8 Hz, 1 H), 7.00 (dd, J = 7.3, 1.5 Hz, 1 H), 6.86 (t, J = 7.6 Hz, 1 H), 6.79 (d, J = 7.9 Hz, 1 H), 6.13 (dd, J = 10.0, 1.8 Hz, 1 H), 5.9 (m, 1 H), 5.80 (dd, J = 10.0, 3.5 Hz, 1 H). ^{13}C-NMR: δ = 153.4, 141.0, 129.7, 128.9, 128.6, 127.2, 126.8, 125.1, 124.2, 121.5, 121.4, 116.2, 77.4.

*2-tert-Butyl-2*H-*chromene* (**5i**).: As above, using salicylaldehyde and (*E*)-3,3-dimethyl-1-butenylboric acid; 96%. ^{1}H-NMR: δ = 7.10 (td, J = 7.6, 1.8 Hz, 1 H), 6.94 (dd, J = 7.3, 1.8 Hz, 1 H), 6.81 (td, J = 7.3, 1.2 Hz, 1 H), 6.78 (d, J = 7.9 Hz, 1 H), 6.46 (dd, J = 10.3, 2.1 Hz, 1 H), 5.72 (dd, J = 10.3, 3.2 Hz, 1 H), 4.57 (symm. m, 1 H), 1.03 (s, 9 H). ^{13}C-NMR: δ = 154.9, 129.3, 126.5, 125.2, 122.9, 121.7, 120.7, 115.4, 83.3, 37.0, 25.6.

*2-Phenyl-3-methyl-2*H-*chromene* (**5j**): As above, using salicylaldehyde and (*E*)-2-phenyl-1-propenylboric acid; 75%. ^{1}H-NMR: δ = 7.5 – 7.3 (m, 5 H), 7.05 (td, J = 7.6, 2.9 Hz, 1 H), 6.99 (dd, J = 7.6, 2.0 Hz, 1 H), 6.85 (td, J = 7.3, 1.2 Hz, 1 H), 6.72 (d, J = 8.1 Hz, 1 H), 6.37 (s, 1 H), 5.68 (s, 1 H), 1.72 (s, 3 H). ^{13}C-NMR: δ = 151.8, 139.5, 132.7, 128.9, 128.7, 127.8, 125.9, 122.2, 121.2, 120.2, 115.9, 81.4, 20.2.

*2-(7-Octynyl)-2*H-*chromene* (**5k**): As above, using salicylaldehyde and (*E*)-dec-1-en-9-ynylboric acid; 95%. ^{1}H-NMR: δ = 7.09 (t, J = 8.2 Hz, 1 H), 6.95 (dd, J = 7.4, 2.0 Hz, 1 H), 6.84 (td, J =7.4, 1.2 Hz, 1 H), 6.78 (d, J = 8.2 Hz, 1 H), 6.39 (d, J = 9.8 Hz, 1 H), 5.28 (d, J = 9.8, 3.5 Hz, 1 H), 4.8 (m, 1 H), 2.19 (td, J = 7.0, 2.7 Hz, 2 H), 1.95 (t, J = 2.7 Hz, 1 H), 1.9 – 1.3 (m, 10 H). ^{13}C-NMR: δ = 153.7, 129.3, 126.6, 126.2, 124.2, 122.2, 121.1, 116.2, 84.9, 75.4, 68.4, 35.6, 29.2, 28.9, 28.7, 25.0, 18.7.

1,6-Di(2-chromeyl)hexane (**5l**): As above, using salicylaldehyde and (*E*)-dec-1,9-dienylboric acid; 91%. ^{1}H-NMR: δ = 7.09 (td, J = 7.8, 1.6 Hz, 2 H), 6.95 (dd, J = 7.0, 1.6 Hz, 2 H), 6.82 (t, J =7.4, 2 H), 6.76 (d, J = 8.2 Hz, 2 H), 6.38 (d, J = 10.2 Hz, 2 H), 5.66 (d, J = 10.2, 3.5 Hz, 2 H), 4.8 (m, 2 H), 1.9 – 1.3 (m, 12 H). ^{13}C-NMR: δ = 153.7, 129.3, 126.6, 126.2, 124.1, 122.2, 121.1, 116.2, 75.4, 35.6, 29.6, 25.0.

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[1] H.C. Brown, S.K. Gupta, *J. Am. Chem. Soc.* **1972**, *94*, 4370 - 4371; H.C. Brown, T. Hamaoka, N. Ravindran, *J. Am. Chem. Soc*. **1973**, *95*, 5786 - 5788.

[2] N.A. Petasis, I. Akrltopoulou, *Tetradedron Lett*. **1993**, *34*, 583 – 586.

[3] See: S. Bräse, D. Enders, J. Kobberling, F. Avemaria, *Angew. Chem. Int. Ed*. **1998**, *37*, 3413 – 3415.