ELECTRONIC SUPPLEMENTARY INFORMATION

Catalytic Asymmetric Synthesis of Chromenes and tetrahydroquinolines via Sequential Allylic Alkylation and Intramolecular Heck Coupling

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General procedures:

$^1$H NMR and $^{13}$C NMR spectra were recorded on a Varian AMX400 (400 and 100 MHz, respectively), a Varian VXR300 (300 and 75 MHz, respectively), or a Varian VXR200 NMR spectrometer (200 MHz and 75 MHz, respectively) with CDCl$_3$ as solvent. Chemical shifts were determined relative to the residual solvent peaks (CHCl$_3$, $\delta = 7.26$ ppm for $^1$H NMR, $\delta = 77.0$ ppm for $^{13}$C NMR). The following abbreviations are used to indicate signal multiplicity: s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet; br, broad. Carbon assignments are based on APT $^{13}$C-NMR experiments. Enantiomeric excesses were determined by chiral HPLC using a Shimadzu LC-10ADVP HPLC equipped with a Shimadzu SPD-M10AVP diode array detector or by capillary GC analysis (HP 6890, CP-Chiralsil-Dex-CB column (25 m x 0.25 mm) or Chiraldex B-PM (30 m x 0.25 mm x 0.25 $\mu$m)) using a flame ionization detector, in comparison with racemic products. Racemic products were obtained by the same procedure as the enantioselective allylic alkylation only using CuBr·SMe$_2$ (10 mol%), PPh$_3$ (20 mol%) and the corresponding Grignard reagent (1.70 eq.) at -80 °C in CH$_2$Cl$_2$. The ratio of regioisomers branch/linear (AAA) and exocyclic/endocyclic ratio (H eck coupling) were determined by $^1$H NMR. Optical rotations were measured on a Schmidt + Haensch polarimeter (Polartronic MH8) with a 10 cm cell ($c$ given in g/100 mL) at 20 °C. Thin-layer chromatography (TLC) was performed on Merck TLC Silica gel 60 Kieselguhr F$^{254}$. Flash chromatography was performed on silica gel Merck Type 9385 230-400 mesh. All reactions were carried out under a nitrogen atmosphere using oven dried glassware and using standard Schlenk techniques. CH$_2$Cl$_2$ was dried and distilled over calcium hydride. CuBr·SMe$_2$, Hoveyda-Grubbs 2$^\text{nd}$ generation catalysts, Wilkinson catalysts, ($R,R$)-Taniaphos and commercially available reagents were purchased from Aldrich, and used without further purification. Grignard reagents were purchased from Aldrich (MeMgBr, EtMgBr) or prepared from the corresponding alkyl bromides and magnesium turnings in Et$_2$O following standard procedures. Grignard reagents were titrated using $s$-BuOH and catalytic amounts of 1,10-phenanthroline.

Synthesis of Allylic bromides 1 and 2

$$\text{K}_2\text{CO}_3\text{(1.5 equiv), MeCN, reflux}$$

(E)-2-(4-Bromobut-2-enyloxy)-1-bromobenzene (1)

A suspension of o-bromophenol (10 mmol, 1.16 mL), 1,4-dibromobut-2-ene (40 mmol, 8.6 g) and $\text{K}_2\text{CO}_3$ (15 mmol, 2.05 g) in CH$_3$CN (100 mL) was heated at reflux temperature for 7 h. The reaction mixture was then concentrated and H$_2$O (100 mL) and Et$_2$O (100 mL) were added. The
aqueous layer was separated and extracted with Et<sub>2</sub>O (50 mL). The combined organic layer were dried (MgSO<sub>4</sub>), filtered and concentrated in vacuo. Purification of the residue by flash chromatography (SiO<sub>2</sub>, Et<sub>2</sub>O/n-pentane gradient (1:99 to 5:95), R<sub>f</sub> = 0.4) afforded 1 (2.9 g, 95% yield) as a colorless oil. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.54 (dd, <i>J</i> = 7.8 and 1.6 Hz, 1H), 7.27-7.23 (m, 1H), 6.88-6.83 (m, 2H), 6.15 (m, 1H), 6.01 (m, 1H), 4.58 (d, <i>J</i> = 4.9 Hz, 2H), 4.00 (d, <i>J</i> = 7.4 Hz, 2H) ppm. <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δ 154.7, 133.5, 129.4, 129.2, 128.4, 122.2, 113.6, 112.4. 68.2, 31.6. HRMS (EI, <i>m/z</i>): calcd for C<sub>10</sub>H<sub>10</sub>Br<sub>2</sub>O+: 307.9058; found: 307.9064.

(E)-N-(4-Bromobut-2-enyl)-N-(2-bromophenyl)-4-methylbenzenesulfonamide (2)

Prepared from o-bromophenyltosylamide (7.36 mmol, 2.4 g) following the procedure described for 1 (Reaction time = 16 h). Purification by column chromatography (SiO<sub>2</sub>, Et<sub>2</sub>O/n-pentane gradient (5:95 to 15:85), R<sub>f</sub> = 0.4) afforded 2 (2.52 g, 75% yield) as a white solid, mp 90-91 °C. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.66 (d, <i>J</i> = 8.2 Hz, 2H), 7.59 (d, <i>J</i> = 8.2 Hz, 1H), 7.30-7.24 (m, 3H), 7.21-7.16 (m, 1H), 7.11 (d, <i>J</i> = 7.9 Hz, 1H), 5.81-5.75 (m, 1H), 5.68-5.60 (m, 1H), 4.18 (m, 2H), 3.80 (d, <i>J</i> = 7.8 Hz, 2H), 2.44 (s, 3H) ppm. <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δ 143.7, 137.5, 136.7, 133.9, 132.6, 131.0, 129.9, 129.5, 129.3, 127.9, 127.8, 125.6, 52.2, 31.2, 21.6. HRMS (EI, <i>m/z</i>): calcd for C<sub>17</sub>H<sub>17</sub>Br<sub>2</sub>NO<sub>2</sub>S+: 458.9326; found: 458.9337.

**General procedure A: Enantioselective Cu-catalyzed synthesis of compounds 3 and 4**

In a dry Schlenk tube equipped with septum and stirring bar, CuBr·SMe<sub>2</sub> (0.01 mmol, 2.05 mg, 5.0 mol%) and (R,R)-Taniaphos (L<sub>1</sub>) (0.012 mmol, 8.25 mg, 6 mol%) were dissolved in CH<sub>2</sub>Cl<sub>2</sub> (2.0 mL) and stirred under nitrogen atmosphere at room temperature for 20 min. The mixture was cooled to -80 °C and a solution of Grignard reagent (solution in Et<sub>2</sub>O, 1.7 eq.) in CH<sub>2</sub>Cl<sub>2</sub> (1.0 mL) was added dropwise over 30 min via a syringe pump. Subsequently, a solution of allylic bromide 1 or 2 (0.2 mmol) in CH<sub>2</sub>Cl<sub>2</sub> (1.0 mL) was added dropwise over 1 h via syringe pump. Once the addition was complete, the resulting mixture was stirred at -80 °C for 16h. The reaction was quenched by addition of MeOH (2.0 mL) and the mixture was allowed to warm up to rt. Saturated aqueous NH<sub>4</sub>Cl solution (2 mL) was added and the organic phase was separated. The aqueous phase was extracted with CH<sub>2</sub>Cl<sub>2</sub> (2 x 10 mL). The combined organic phases were dried over MgSO<sub>4</sub> and concentrated under reduced pressure to yield the crude product which was purified by flash chromatography (SiO<sub>2</sub>, EtOAc/Pentane). In accordance with the results
obtained in our previous work, the absolute configuration of these compounds is assumed to be (S).¹

(+)-1-Bromo-2-(2-methylbut-3-enyloxy)benzene (3a)

The title compound was prepared from 1 (3.0 mmol, 918 mg) following general procedure A. Purification by column chromatography (SiO₂, EtOAc/Pentane 1:99, R_f = 0.60) afforded 3a (88% yield, 634 mg, 99% ee, [α]D = +8.6 (c 1.0 in CHCl₃)) as a colorless oil. Enantiomeric excess determined for Heck product 5a. ¹H NMR (400 MHz, CDCl₃) δ 7.53 (dd, J = 7.8 and 1.6 Hz, 1H), 7.24 (m, 1H), 6.84 (m, 2H), 5.92 (m, 1H), 5.13 (m, 2H), 3.95 (dd, J = 8.9 and 6.0 Hz, 1H), 3.83 (dd, J = 8.9 and 7.0 Hz, 1H), 2.75 (m, 1H), 1.20 (d, J = 6.8 Hz, 3H) ppm. ¹³C NMR (101 MHz, CDCl₃) δ 155.3, 140.1, 133.3, 128.3, 121.7, 114.9, 113.2, 73.4, 37.4, 16.5. HRMS (EI, m/z): calculated for C₁₁H₁₃BrO+: 240.0150; found: 240.0136.

(+)-1-bromo-2-(2-ethylbut-3-enyloxy)benzene (3b)

The title compound was prepared from 1 (0.40 mmol, 120 mg) following general procedure A. Purification by column chromatography (SiO₂, EtOAc/Pentane 1:99, R_f = 0.7) afforded 3b (97% yield, 97 mg, 99% ee, [α]D²⁰ = +28.0 (c 1.0 in CHCl₃)) as a colorless oil. Enantiomeric excess determined by chiral HPLC analysis, Chiralcel OD-H (99.75% n-heptane/0.25% i-PrOH), 40 °C, retention times (min) 13.2 (major) and 13.7 (minor). ¹H NMR (400 MHz, CDCl₃) δ 7.53 (dd, J = 7.9 and 1.6 Hz, 1H), 7.24 (m, 1H), 6.87 (dd, J = 8.2 and 1.3 Hz, 1H), 6.82 (m, 1H), 5.80 (m, 1H), 5.16 (m, 2H), 3.90-3.99 (m, 2H), 2.49 (m, 1H), 1.75 (m, 1H), 1.48 (m, 1H), 0.96 (t, J = 7.5 Hz, 3H) ppm. ¹³C NMR (101 MHz, CDCl₃) δ 155.4, 138.9, 133.3, 128.3, 121.6, 116.4, 113.2, 112.4, 72.0, 45.2, 24.0, 11.4 ppm. HRMS (APCI+, m/z): calculated for C₁₂H₁₆BrO [M+H⁺]: 255.0385, found: 255.0381.

(+)-1-bromo-2-(2-vinylhex-5-enyloxy)benzene (3c)

The title compound was prepared from 1 (0.65 mmol, 200 mg) following general procedure A. Purification by column chromatography (SiO₂, EtOAc/Pentane 1:99, Rₚ = 0.8) afforded 3c (86% yield, 157 mg, 96% ee, [α]D²⁰ = +7.4 (c 1.0 in CHCl₃)) as a colorless oil. Enantiomeric excess determined by chiral HPLC analysis, Chiralcel OD-H (99.9 % n-heptane/0.1% i-PrOH, FL= 0.25 mL min⁻¹), 40 °C, retention times (min) 40.7 (major) and 43.1 (minor). ¹H NMR (400 MHz, CDCl₃) δ 7.53 (dd, J = 7.9 and 1.6 Hz, 1H), 7.24 (m, 1H), 6.87 (dd, J = 8.2 and 1.4 Hz, 1H), 6.82 (m, 1H), 5.81 (m, 2H), 5.17 (m, 2H), 5.00 (m, 2H), 4.00-3.90 (m, 2H), 2.60 (m, 1H), 2.18 (m, 1H), 2.10 (m, 1H), 1.81 (m, 1H), 1.57 (m, 1H) ppm. ¹³C NMR (101 MHz, CDCl₃) δ 155.4, 138.8, 138.5, 133.3, 128.3, 121.7, 116.7, 114.7, 113.2, 112.4, 72.2, 43.0, 31.0, 30.2 ppm. HRMS (APCI+, m/z): calculated for C₁₄H₁₈BrO [M+H⁺]: 281.0541, found: 281.0536. 

(+)-1-bromo-2-(2-vinylhept-6-enyloxy)benzene (3d)

The title compound was prepared from 1 (1.31 mmol, 400 mg) following general procedure A. Purification by column chromatography (SiO₂, EtOAc/Pentane 1:99, Rₚ = 0.8) afforded 3d (90% yield, 348 mg, 95% ee, [α]D²⁰ = +28.0 (c 1.2 in CHCl₃)) as a colorless oil. Enantiomeric excess determined by chiral HPLC analysis, Chiralcel OD-H (99.9 % n-heptane/0.1% i-PrOH, FL= 0.25 mL min⁻¹), 40 °C, retention times (min) 40.0 (major) and 45.9 (minor). ¹H NMR (400 MHz, CDCl₃) δ 7.52 (dd, J = 7.9 and 1.6 Hz, 1H), 7.24 (m, 1H), 6.86 (dd, J = 8.3 and 1.3 Hz, 1H), 6.81 (m, 1H), 5.81 (m, 2H), 5.16 (m, 2H), 5.00 (m, 2H), 3.98-3.88 (m, 2H), 2.57 (m, 1H), 2.09 (m, 2H), 1.71 (m, 1H), 1.45 (m, 3H) ppm. ¹³C NMR (101 MHz, CDCl₃) δ 155.4, 139.0, 138.7, 133.3, 128.3, 121.7, 116.4, 114.5, 113.2, 112.4, 72.3, 43.5, 33.8, 30.6, 26.2 ppm. HRMS (APCI+, m/z): calculated for C₁₅H₂₀BrO [M+H⁺]: 295.0698, found: 295.0692. 

(+)-1-bromo-2-(2-vinyloct-7-enyloxy)benzene (3e)

The title compound was prepared from 1 (0.65 mmol, 200 mg) following general procedure A. Purification by column chromatography (SiO₂, EtOAc/Pentane 1:99, Rₚ = 0.8) afforded 3e (94% yield, 190 mg, 97% ee, [α]D²⁰ = +24.0 (c 1.0 in CHCl₃)) as a colorless oil. Enantiomeric excess determined by chiral HPLC analysis, Chiralcel OD-H (99.9 % n-heptane/0.1% i-PrOH, FL= 0.25
mL min⁻¹), 40 °C, retention times (min) 41.0 (major) and 44.0 (minor). ¹H NMR (400 MHz, CDCl₃) δ 7.52 (dd, J = 7.9 and 1.6 Hz, 1H), 7.24 (m, 1H), 6.87 (dd, J = 8.2 and 1.2 Hz, 1H), 6.82 (m, 1H), 5.81 (m, 2H), 5.15 (m, 2H), 4.95 (m, 2H), 3.98-3.88 (m, 2H), 2.56 (m, 1H), 2.07 (m, 2H), 1.71 (m, 1H), 1.45 (m, 5H) ppm. ¹³C NMR (101 MHz, CDCl₃) δ 155.4, 139.1, 139.0, 133.3, 128.3, 121.7, 116.4, 114.3, 113.1, 112.3, 72.3, 43.5, 33.7, 30.9, 28.9, 26.4 ppm. HRMS (APCI+, m/z): calculated for C₁₆H₂₂BrO [M+H⁺]: 309.0854, found: 309.0849.

(+)-(2-bromophenyl)-4-methyl-N-(2-methylbut-3-enyl)benzenesulfonamide (4a)

The title compound was prepared from 2 (1.0 mmol, 459 mg) following general procedure A. Purification by column chromatography (SiO₂, EtOAc/Pentane 10:90, Rᵣ = 0.65) afforded 4a (72% yield, 282 mg, 99% ee, [α]D²⁰ = +1.6 (c 14.9 in CHCl₃)) as a white solid, mp 78-79 °C. Enantiomeric excess determined by chiral HPLC analysis, Chiralpak AD (99% n-heptane/1% i-PrOH), 40 °C, retention times (min) 19.3 (major) and 20.9 (minor). ¹H NMR (400 MHz, CDCl₃) δ 7.57 (m, 3H), 7.25 (m, 4H), 7.16 (m, 1H), 5.67, (m, 1H), 4.97 (m, 2H), 3.53 (m, 2H), 2.43 (s major peak, 3H), 2.42 (s minor peak, 3H), 2.34 (m , minor peak, 1H), 1.07 (d, J = 6.7 Hz, major peak, 3H), 1.02 (d, J = 6.8 Hz, minor peak, 3H) ppm. ¹³C NMR (101 MHz, CDCl₃) δ 143.5, 143.4, 141.1, 140.9, 138.2, 136.7, 136.4, 134.1, 133.4, 132.4, 129.6, 129.5, 129.4, 128.0, 127.9, 127.8, 127.7, 125.5, 124.8, 114.8, 114.7, 56.5, 37.0, 21.6, 18.0 ppm. HRMS (ESI+, m/z): calculated for C₁₈H₂₁BrNO₂S [M+H⁺]: 394.0476, found: 394.0471.

(+)-(2-bromophenyl)-N-(2-ethylbut-3-enyl)-4-methylbenzenesulfonamide (4b)

The title compound was prepared from 2 (0.30 mmol, 140 mg) following general procedure A. Purification by column chromatography (SiO₂, EtOAc/Pentane 10:90, Rᵣ = 0.7) afforded 4b (99% yield, 123 mg, 99% ee, [α]D²⁰ = +26.0 (c 1.0 in CHCl₃)) as a waxy solid. Enantiomeric excess determined for Heck product 6b. ¹H NMR (400 MHz, CDCl₃) δ 7.56 (m, 3H), 7.28-7.11 (m, 5H), 5.55-5.39 (m, 1H), 5.01-4.86 (m, 2H), 3.65 (m, 1H), 3.48 (m, 1H), 2.41 (m, 3H), 2.13 (m, minor peak, 1H), 1.89 (m, major peak, 1H), 1.68 (m, major peak, 1H), 1.54 (m, minor peak, 1H), 1.20 (m, 1H), 0.82 (d, J = 7.3 Hz, minor peak, 3H), 0.78 (d, J = 7.4 Hz, major peak, 3H) ppm. ¹³C NMR (101 MHz, CDCl₃) δ 143.4, 139.5, 139.4, 138.3, 138.0, 136.6, 136.5, 134.1, 134.0, 133.6, 132.5, 129.6, 129.5, 129.4, 127.9, 127.8, 127.7, 127.6, 125.5, 124.7, 116.8, 116.6, 55.4, 55.0, 45.3, 44.5, 25.0, 24.9, 21.6, 11.3, 11.2 ppm. HRMS (APCI+, m/z): calculated for C₁₉H₂₃BrNO₂S [M+H⁺]: 408.0633, found: 408.0638.
(+)-N-(2-bromophenyl)-4-methyl-N-(2-vinylhex-5-enyl)benzenesulfonamide (4c)

The title compound was prepared from 2 (0.50 mmol, 230 mg) following general procedure A. Purification by column chromatography (SiO₂, EtOAc/Pentane 10:90, Rₜ = 0.7) afforded 4c (87% yield, 187 mg, 96% ee, [α]₀^D = +8.0 (c 1.0 in CHCl₃)) as a colorless oil. Enantiomeric excess determined by chiral HPLC analysis, Chiralpak AD (99.5 % n-heptane/0.5% i-PrOH), 40 °C, retention times (min) 27.9 (major) and 31.6 (minor). ¹H NMR (400 MHz, CDCl₃) δ 7.60-7.53 (m, 3H), 7.28-7.13 (m, 5H), 5.77-5.67 (m, 1H), 5.57-5.39 (m, 1H), 5.02 (m, 1H), 4.96-4.86 (m, 3H), 3.65 (m, 1H), 3.48 (m, 1H), 2.42 (m, 3H), 2.26 (m, minor peak, 1H), 2.00 (m, major peak, 1H), 1.89 (m, 1H), 1.71 (m, 1H), 1.60 (m, 1H), 1.26 (m, 1H) ppm. ¹³C NMR (101 MHz, CDCl₃) δ 143.4, 139.5, 139.4, 138.3, 138.0, 136.6, 136.5, 134.1, 134.0, 133.7, 132.6, 129.6, 129.5, 129.4, 127.9, 127.8, 127.7, 127.6, 125.4, 124.6, 117.1, 116.8, 114.7, 114.5, 55.7, 55.1, 43.1, 42.5, 31.2, 31.1, 31.0, 30.9, 21.6 ppm. HRMS (APCI⁺, m/z): calculated for C₂₁H₂₅BrNO₂S [M+H⁺]: 434.0789, found: 434.0784.

(+)-N-(2-bromophenyl)-4-methyl-N-(2-vinylhept-6-enyl)benzenesulfonamide (4d)

The title compound was prepared from 2 (0.87 mmol, 400 mg) following general procedure A. Purification by column chromatography (SiO₂, EtOAc/Pentane 10:90, Rₜ = 0.7) afforded 4d (86% yield, 234 mg, 95% ee, [α]₀^D = +54.0 (c 1.9 in CHCl₃)) as a colorless oil. Enantiomeric excess determined for Heck product 6d. ¹H NMR (400 MHz, CDCl₃) δ 7.59-7.53 (m, 3H), 7.29-7.13 (m, 5H), 5.80-5.68 (m, 1H), 5.57-5.39 (m, 1H), 5.01-4.87 (m, 4H), 3.65 (m, 1H), 3.48 (m, 1H), 2.42 (m, 3H), 2.25 (m, minor peak, 1H), 1.98 (m, major peak + CH₂, 3H), 1.63 (m, major peak, 1H), 1.50 (m, minor peak, 1H), 1.36 (m, 1H), 1.19 (m, 2H) ppm. ¹³C NMR (101 MHz, CDCl₃) δ 143.5, 139.6, 138.7, 138.0, 136.5, 132.5, 127.9, 127.6, 125.4, 124.7, 116.8, 116.5, 114.5, 114.4, 55.7, 55.1, 43.6, 42.9, 33.7, 31.5, 26.1, 21.6 ppm. HRMS (APCI⁺, m/z): calculated for C₂₂H₂₇BrNO₂S [M+H⁺]: 448.0946, found: 448.0941.
(+)-N-(2-bromophenyl)-4-methyl-N-(2-vinyloct-7-enyl)benzenesulfonamide (4e)

The title compound was prepared from 2 (0.50 mmol, 230 mg) following general procedure A. Purification by column chromatography (SiO2, EtOAc/Pentane 10:90, Rf = 0.75) afforded 4e (68% yield, 203 mg, 98% ee, [α]D20 = +32.6 (c 1.2 in CHCl3)) as a colorless oil. Enantiomeric excess determined for Heck product 6e. 1H NMR (400 MHz, CDCl3) δ 7.60-7.53 (m, 3H), 7.28-7.11 (m, 5H), 5.82-5.71 (m, 1H), 5.56-5.39 (m, 1H), 5.00-4.86 (m, 4H), 3.65 (m, 1H), 3.48 (m, 1H), 2.42 (m, 3H), 2.21 (m, minor peak, 1H), 1.99 (m, major peak + CH2, 3H), 1.63 (m, major peak, 1H), 1.47 (m, minor peak, 1H), 1.33-1.11 (m, 5H) ppm. 13C NMR (101 MHz, CDCl3) δ 143.4, 139.8, 139.7, 139.0, 138.3, 138.0, 136.7, 136.5, 134.1, 134.0, 133.7, 132.5, 129.6, 129.5, 129.4, 127.9, 127.8, 127.7, 127.6, 125.5, 124.7, 116.7, 116.4, 114.2, 55.6, 55.2, 43.6, 42.9, 33.6, 31.9, 31.8, 28.9, 28.8, 26.3, 26.2, 21.6 ppm. HRMS (APCI+, m/z): calculated for C23H29BrNO2S [M+H+]: 462.1102, found: 462.1097.

General procedure B: Synthesis of compounds 5 and 6 by intramolecular Heck reaction

TBAB (1 g), TBAA (0.45 g, 1.5 mmol), Pd(OAc)2 (3 mol%) and the corresponding AAA product (3 or 4) were stirred and heated at 100 °C for the indicated time (see Table 2). Water (3 mL) and EtOAc (3 mL) were added and, after cooling to r.t., the organic phase separated. The aqueous phase was extracted with EtOAc (2 x 5 mL). The combined organic phases were dried over MgSO4 and concentrated under reduced pressure to yield the crude product which was purified by flash chromatography on silica gel, EtOAc/Pentane.

(+)-3-methyl-4-methylenechromene (5a)

The title compound was prepared from 3a (0.29 mmol, 70 mg) following general procedure B. Reaction time: 15 min. Purification by column chromatography (SiO2, EtOAc/Pentane 1:99, Rf = 0.4) afforded 5a (93% yield, 43 mg, ratio exo:end = 95:5, >99% ee, [α]D20 = +18.3 (c 0.6 in
CHCl\(_3\)\) as a colorless oil. Enantiomeric excess determined by chiral GC analysis, Chiraldex B-PM column (30 m x 0.25 mm), 5 min isothermic 50 °C then 2 °C/min gradient to 175 °C, retention times (min) 44.5 (major) and 44.9 (minor). \(^1\)H NMR (400 MHz, CDCl\(_3\) δ 7.57 (dd, \(J = 7.9\) and 1.6 Hz, 1H), 7.20-7.14 (m, 1H), 6.93-6.85 (m, 1H), 6.84 (dd, \(J = 8.2\) and 1.0 Hz, 1H), 5.50 (d, \(J = 0.7\) Hz, 1H), 4.94 (d, \(J = 1.4\) Hz, 1H), 4.19 (dd, \(J = 10.5\) and 3.5 Hz, 1H), 3.91 (dd, \(J = 10.5\) and 7.3 Hz, 1H), 2.73 (m, 1H), 1.20 (d, \(J = 6.9\) Hz, 3H) ppm. \(^13\)C NMR (101 MHz, CDCl\(_3\) δ 154.1, 142.6, 129.3, 124.9, 121.3, 120.7, 117.1, 105.2, 71.8, 34.0, 15.6 ppm. HRMS (EI, \(m/z\)) calculated for C\(_{11}\)H\(_{12}\)O+: 160.0888, found: 160.0883.

(-)-3-ethyl-4-methylenechromene (5b)

The title compound was prepared from 3b (0.27 mmol, 70 mg) following general procedure B. Reaction time: 15 min. Purification by column chromatography (SiO\(_2\), EtOAc/Pentane 1:99, \(R_f = 0.5\)) afforded 5b (96% yield, 45 mg, ratio exo:endo = 98:2, 98% ee, \([\alpha]_D^{20} = -18.6\) (c 1.0 in CHCl\(_3\)\)) as a colorless oil. Enantiomeric excess determined by chiral GC analysis, Chiraldex B-PM column (30 m x 0.25 mm), 5 min isothermic 50 °C then 2 °C/min gradient to 175 °C, retention times (min) 47.2 (minor) and 47.7 (major). \(^1\)H NMR (400 MHz, CDCl\(_3\) δ 7.56 (dd, \(J = 7.9\) and 1.6 Hz, 1H), 7.19-7.15 (m, 1H), 6.92-6.88 (m, 1H), 6.83 (dd, \(J = 8.2\) and 1.1 Hz, 1H), 5.52 (s, 1H), 4.89 (s, 1H), 4.20 (d, \(J = 3.1\) Hz, 2H), 2.38 (m, 1H), 1.59 (m, 2H), 0.98 (t, \(J = 7.4\) Hz, 3H) ppm. \(^13\)C NMR (101 MHz, CDCl\(_3\) δ 153.9, 140.8, 129.3, 125.0, 121.0, 120.6, 117.0, 107.0, 69.9, 42.2, 23.4, 11.8 ppm. HRMS (APCI+, \(m/z\)): calculated for C\(_{12}\)H\(_{15}\)O \([M+H^+]\): 175.1123, found: 175.1118.

(+)-3-(but-3-enyl)-4-methylenechromene (5c)

The title compound was prepared from 3c (0.25 mmol, 70 mg) following general procedure B. Reaction time: 1.5 h. Purification by column chromatography (SiO\(_2\), EtOAc/Pentane 1:99, \(R_f = 0.7\)) afforded 5c (84% yield, 42 mg, ratio exo:endo = >99:1, 96% ee, \([\alpha]_D^{20} = +42.6\) (c 1.0 in CHCl\(_3\)\)) as a colorless oil. Enantiomeric excess determined by chiral GC analysis, Chiraldex B-PM column (30 m x 0.25 mm), 5 min isothermic 50 °C then 2 °C/min gradient to 175 °C, retention times (min) 57.1 (minor) and 57.4 (major). \(^1\)H NMR (400 MHz, CDCl\(_3\) δ 7.56 (dd, \(J = 7.9\) and 1.6 Hz, 1H), 7.19-7.15 (m, 1H), 6.92-6.88 (m, 1H), 6.83 (dd, \(J = 8.2\) and 1.1 Hz, 1H), 5.87-5.76 (m, 1H), 5.52 (s, 1H), 5.06-4.97 (m, 2H), 4.89 (s, 1H), 4.20 (d, \(J = 2.9\) Hz, 2H), 2.52 (m, 1H), 2.15 (m, 2H), 1.65 (m, 2H) ppm. \(^13\)C NMR (101 MHz, CDCl\(_3\) δ 153.8, 140.7, 138.3,
129.4, 125.1, 120.8, 120.7, 117.1, 115.0, 107.2, 70.1, 39.8, 31.2, 29.5 ppm. HRMS (APCI+, m/z): calculated for C_{14}H_{17}O [M+H^+]: 201.1279, found: 201.1274.

(-)-4-methylene-3-(pent-4-enyl)chromene (5d)

![Chemical structure of 5d](image)

The title compound was prepared from 3d (0.81 mmol, 240 mg) following general procedure B. Reaction time: 1.5 h. Purification by column chromatography (SiO\textsubscript{2}, EtOAc/Pentane 1:99, \(R_f = 0.7\)) afforded 5d (92% yield, 160 mg, ratio exo:endo = >99:1, 95% ee, [\(\alpha\)]\textsubscript{D}\textsuperscript{20} = -20.2 (c 0.4 in CHCl\textsubscript{3})) as a colorless oil. Enantiomeric excess determined for RCM product 9. \(^1\)H NMR (400 MHz, CDCl\textsubscript{3}) \(\delta\) 7.56 (dd, \(J = 7.9\) and 1.6 Hz, 1H), 7.20-7.15 (m, 1H), 6.92-6.88 (m, 1H), 5.86-5.76 (m, 1H), 5.51 (s, 1H), 5.03-4.93 (m, 2H), 4.89 (s, 1H), 4.19 (d, \(J = 3.0\) Hz, 2H), 2.49 (m, 1H), 2.07 (m, 2H), 1.60-1.45 (m, 4H) ppm. \(^{13}\)C NMR (101 MHz, CDCl\textsubscript{3}) \(\delta\) 153.9, 141.0, 138.6, 129.4, 125.1, 120.9, 120.7, 117.0, 114.6, 106.9, 70.1, 40.4, 33.7, 29.9, 26.6 ppm. HRMS (APCI+, m/z): calculated for C\textsubscript{15}H\textsubscript{19}O [M+H^+]: 215.1436, found: 215.1430.

(-)-3-(hex-5-enyl)-4-methylenechromene (5e)

![Chemical structure of 5e](image)

The title compound was prepared from 3e (0.32 mmol, 100 mg) following general procedure B. Reaction time: 1.5 h. Purification by column chromatography (SiO\textsubscript{2}, EtOAc/Pentane 1:99, \(R_f = 0.7\)) afforded 5e (89% yield, 65 mg, ratio exo:endo = >99:1, 99% ee, [\(\alpha\)]\textsubscript{D}\textsuperscript{20} = -27.0 (c 1.0 in CHCl\textsubscript{3})) as a colorless oil. Enantiomeric excess determined by chiral HPLC analysis, Chiralcel OJ (99.8 % n-heptane/0.2% i-PrOH), 40 °C, retention times (min) 9.9 (minor) and 10.1 (major). \(^1\)H NMR (400 MHz, CDCl\textsubscript{3}) \(\delta\) 7.55 (dd, \(J = 7.9\) and 1.6 Hz, 1H), 7.19-7.14 (m, 1H), 6.91-6.87 (m, 1H), 6.83 (dd, \(J = 8.2\) and 1.1 Hz, 1H), 5.85-5.74 (m, 1H), 5.50 (s, 1H), 5.00-4.92 (m, 2H), 4.88 (s, 1H), 4.18 (d, \(J = 3.0\) Hz, 2H), 2.47 (m, 1H), 2.05 (m, 2H), 1.54 (m, 2H), 1.40 (m, 4H) ppm. \(^{13}\)C NMR (101 MHz, CDCl\textsubscript{3}) \(\delta\) 153.9, 141.0, 138.9, 129.4, 125.1, 120.9, 120.7, 117.0, 114.3, 106.8, 70.1, 40.5, 33.7, 30.2, 28.8, 26.7 ppm. HRMS (APCI+, m/z): calculated for C\textsubscript{16}H\textsubscript{21}O [M+H^+]: 229.1592, found: 229.1587.
(+)-3-methyl-4-methylene-1-tosyl-1,2,3,4-tetrahydroquinoline (6a)

The title compound was prepared from 4a (0.24 mmol, 95 mg) following general procedure B. Reaction time: 15 min. Purification by column chromatography (SiO₂, EtOAc/Pentane 10:90, Rₚ = 0.4) afforded 6a (92% yield, 68 mg, ratio exo:endo = 95:5, 99% ee, [α]D²⁰ = 2.8 (c 1.0 in CHCl₃)) as a colorless oil. Enantiomeric excess determined by chiral HPLC analysis, Chiralpak AD (99.5 % n-heptane/0.5% i-PrOH), 40 ºC, retention times (min) 23.3 (major) and 30.2 (minor).

1H NMR (400 MHz, CDCl₃) δ 7.71 (d, J = 8.4 Hz, 1H), 7.55-7.51 (m, 3H), 7.26-7.17 (m, 3H), 7.11-7.07 (m, 1H), 5.40 (d, J = 1.7 Hz, 1H), 4.86 (d, J = 1.8 Hz, 1H), 4.12 (dd, J = 13.3 and 4.9 Hz, 1H), 3.30 (dd, J = 13.3 and 10.4 Hz, 1H), 2.52 (m, 1H), 2.37 (s, 3H), 1.10 (d, J = 6.8 Hz, 3H) ppm. 13C NMR (101 MHz, CDCl₃) δ 143.8, 143.6, 137.1, 136.2, 129.6, 128.4, 128.3, 127.0, 125.0, 124.9, 123.6, 108.6, 52.5, 33.3, 21.5, 17.6 ppm. HRMS (APCI+, m/z): calculated for C₁₈H₁₉NNaO₂S [M+H⁺]: 336.1034, found: 336.1029.

(-)-3-ethyl-4-methylene-1-tosyl-1,2,3,4-tetrahydroquinoline (6b)

The title compound was prepared from 4b (0.21 mmol, 86 mg) following general procedure B. Reaction time: 15 min. Purification by column chromatography (SiO₂, EtOAc/Pentane 10:90, Rₚ = 0.6) afforded 6b (93% yield, 63 mg, ratio exo:endo = 98:2, 99% ee, [α]D²⁰ = -26.6 (c 1.0 in CHCl₃)) as a colorless oil. Enantiomeric excess determined by chiral HPLC analysis, Chiralcel OJ-H (99 % n-heptane/1% i-PrOH), 40 ºC, retention times (min) 33.3 (major) and 41.4 (minor).

1H NMR (400 MHz, CDCl₃) δ 7.66 (dd, J = 8.3 and 0.9 Hz, 1H), 7.57-7.55 (m, 2H), 7.49 (dd, J = 7.9 and 1.5 Hz, 1H), 7.20-7.18 (m, 3H), 7.07 (m, 1H), 5.33 (s, 1H), 4.79 (d, J = 1.1 Hz, 1H), 4.01 (dd, J = 13.1 and 4.7 Hz, 1H), 3.65 (dd, J = 13.1 and 8.0 Hz, 1H), 2.42-2.40 (m, 1H), 2.37 (s, 3H), 1.59-1.40 (m, 2H), 0.92 (t, J = 7.4 Hz, 3H) ppm. 13C NMR (101 MHz, CDCl₃) δ 143.6, 142.5, 137.0, 136.2, 129.6, 128.4, 128.3, 127.1, 125.3, 124.7, 122.7, 109.6, 50.5, 41.1, 25.2, 21.5, 11.3 ppm. HRMS (APCI+, m/z): calculated for C₁₉H₂₂NO₂S [M+H⁺]: 328.1371, found: 328.1372.

(-)-3-(but-3-enyl)-4-methylene-1-tosyl-1,2,3,4-tetrahydroquinoline (6c)
The title compound was prepared from 4c (0.28 mmol, 120 mg) following general procedure B. Reaction time: 1 h. Purification by column chromatography (SiO₂, EtOAc/Pentane 10:90, Rf = 0.7) afforded 6c (87% yield, 86 mg, ratio exo:endo = 98:2, 97% ee, [α]D²⁰ = -7.2 (c 0.7 in CHCl₃)) as a colorless oil. Enantiomeric excess determined by chiral HPLC analysis, Chiracel OJ-H (99 % n-heptane/1% i-PrOH), 40 °C, retention times (min) 36.1 (major) and 41.0 (minor).

1H NMR (400 MHz, CDCl₃) δ 7.66 (dd, J = 8.4 and 0.9 Hz, 1H), 7.59-7.56 (m, 2H), 7.49 (dd, J = 7.9 and 1.5 Hz, 1H), 7.21-7.19 (m, 3H), 7.07 (m, 1H), 5.82-5.72 (m, 1H), 5.34 (s, 1H), 5.06-4.98 (m, 2H), 4.81 (d, J = 1.0 Hz, 1H), 3.98 (dd, J = 13.1 and 4.6 Hz, 1H), 3.71 (dd, J = 13.1 and 7.5 Hz, 1H), 2.54 (m, 1H), 2.38 (s, 3H), 2.10 (m, 2H), 1.56 (m, 2H) ppm. 13C NMR (101 MHz, CDCl₃) δ 143.6, 142.6, 137.9, 137.0, 136.1, 129.6, 128.4, 127.9, 127.1, 125.4, 124.6, 122.5, 115.2, 109.8, 50.6, 38.9, 31.4, 30.8, 21.5 ppm. HRMS (APCI+, m/z): calculated for C₂₁H₂₄NO₂S [M+H⁺]: 354.1528, found: 354.1522.

(-)-4-methylene-3-(pent-4-enyl)-1-tosyl-1,2,3,4-tetrahydroquinoline (6d)

The title compound was prepared from 4d (0.42 mmol, 190 mg) following general procedure B. Reaction time: 1 h. Purification by column chromatography (SiO₂, EtOAc/Pentane 10:90, Rf = 0.7) afforded 6d (86% yield, 133 mg, ratio exo:endo = 98:2, 97% ee, [α]D²⁰ = -3.2 (c 1.0 in CHCl₃)) as a colorless oil. Enantiomeric excess determined by chiral HPLC analysis, Chiracel OJ-H (99 % n-heptane/1% i-PrOH), 40 °C, retention times (min) 35.4 (major) and 40.6 (minor).

1H NMR (400 MHz, CDCl₃) δ 7.67 (dd, J = 8.3 and 0.9 Hz, 1H), 7.57-7.55 (m, 2H), 7.48 (s, 1H), 7.09-7.05 (m, 1H), 5.83-5.72 (m, 1H), 5.32 (s, 1H), 5.01-4.93 (m, 2H), 4.79 (d, J = 1.1 Hz, 1H), 4.00 (dd, J = 13.1 and 4.7 Hz, 1H), 3.65 (dd, J = 13.1 and 7.9 Hz, 1H), 2.49 (m, 1H), 2.37 (s, 3H), 2.03 (m, 2H), 1.52-1.37 (m, 4H) ppm. 13C NMR (101 MHz, CDCl₃) δ 143.6, 142.7, 138.4, 137.0, 136.1, 129.6, 128.4, 128.2, 127.1, 125.4, 124.7, 122.6, 114.7, 109.6, 50.8, 39.4, 33.6, 31.8, 26.0, 21.5 ppm. HRMS (APCI+, m/z): calculated for C₂₂H₂₅NNaO₂S [M+Na⁺]: 390.1504, found: 390.1498.

(+) 3-(hex-5-enyl)-4-methylene-1-tosyl-1,2,3,4-tetrahydroquinoline (6e)

The title compound was prepared from 4e (0.29 mmol, 135 mg) following general procedure B. Reaction time: 1 h. Purification by column chromatography (SiO₂, EtOAc/Pentane 10:90, Rf = 0.8) afforded 6e (77% yield, 85 mg, ratio exo:endo = 97:3, 98% ee, [α]D²⁰ = +7.6 (c 1.2 in
CHCl₃)) as a white waxy solid. Enantiomeric excess determined by chiral HPLC analysis, Chiralcel OJ-H (99 % n-heptane/1% i-PrOH), 40 °C, retention times (min) 29.5 (major) and 33.1 (minor). ¹H NMR (400 MHz, CDCl₃) δ 7.67 (dd, J = 8.3 and 0.9 Hz, 1H), 7.57-7.55 (m, 2H), 7.48 (dd, J = 7.9 and 1.5 Hz, 1H), 7.23-7.18 (m, 3H), 7.09-7.05 (m, 1H), 5.84-5.74 (m, 1H), 5.32 (s, 1H), 5.01-4.93 (m, 2H), 4.79 (d, J = 1.1 Hz, 1H), 3.99 (dd, J = 13.1 and 4.7 Hz, 1H), 3.64 (dd, J = 13.1 and 7.9 Hz, 1H), 2.47 (m, 1H), 2.37 (s, 3H), 2.03 (m, 2H), 1.56-1.26 (m, 6H) ppm. ¹³C NMR (101 MHz, CDCl₃) δ 143.6, 142.8, 138.7, 137.0, 136.1, 129.6, 128.4, 128.2, 127.1, 125.4, 124.7, 122.7, 114.4, 109.4, 50.8, 39.5, 33.6, 32.2, 28.8, 26.2, 21.5 ppm. HRMS (APCI+, m/z): calculated for C₂₃H₂₇NNaO₂S [M+Na⁺]: 404.1660, found: 404.1655.

**General procedure C: RCM of compounds 5c, 6c and 5d**

![Diagram of reaction](image)

The corresponding diene was dissolved in degassed toluene (2-10 mM) under a N₂ atmosphere. Hoveyda-Grubbs 2nd generation catalyst (5 mol%) was tipped into the solution and then the stirred solution was heated for 6 h at 80 °C. The mixture was cooled down to room temperature and the solvent was removed under reduced pressure to yield the crude product which was purified by flash chromatography on silica gel, EtOAc/Pentane.

(+)-2,3,3a,4-tetrahydrocyclopenta[c]chromene (7)

The title compound was prepared from 5c (0.13 mmol, 25 mg) in toluene (15 mL) following general procedure C. Purification by column chromatography (SiO₂, EtOAc/Pentane 1:99, Rf = 0.7) afforded 7 (84% yield, 18 mg, 96% ee, [α]D²⁰ = +19.6 (c 1.1 in CHCl₃)) as a colorless oil. Volatile compound under vacuum pressure. Enantiomeric excess determined by chiral GC analysis, Chiraldex B-PM column (30 m × 0.25 mm), 5 min isothermic 50 °C then 2 °C/min gradient to 175 °C, retention times (min) 57.9 (major) and 58.4 (minor). ¹H NMR (400 MHz, CDCl₃) δ 7.48 (dd, J = 7.6 and 1.5 Hz, 1H), 7.19-7.11 (m, 1H), 6.90-6.86 (m, 2H), 6.06 (m, 1H), 4.52 (dd, J = 10.1 and 5.1 Hz, 1H), 3.67 (dd, J = 12.0 and 10.1 Hz, 1H), 3.10 (m, 1H), 2.54-2.49 (m, 2H), 2.24-2.17 (m, 1H), 1.49-1.39 (m, 1H) ppm. ¹³C NMR (101 MHz, CDCl₃) δ 153.9, 136.9, 128.8, 125.1, 121.0, 120.7, 119.8, 117.1, 72.4, 41.9, 31.8, 27.5 ppm. HRMS (APCI+, m/z): calculated for C₁₂H₁₃O [M+H⁺]: 173.0966, found: 173.0961.
The title compound was prepared from 6c (0.17 mmol, 60 mg) in toluene (15 mL) following general procedure C. Purification by column chromatography (SiO₂, EtOAc/Pentane 10:90, Rₖ = 0.7) afforded 8 (90% yield, 50 mg, 97% ee, [α]₀⁺²⁰ = +59.6 (c 1.4 in CHCl₃)) as a white waxy solid. Enantiomeric excess determined by chiral HPLC analysis, Chiralpak AD-H (99 % n-heptane/1% i-PrOH), 40 °C, retention times (min) 50.4 (major) and 52.8 (minor). ¹H NMR (400 MHz, CDCl₃) δ 7.82 (d, J = 8.3 Hz, 1H), 7.54-7.52 (m, 3H), 7.22-7.18 (m, 3H), 7.12-7.08 (m, 1H), 6.10 (m, 1H), 4.58 (dd, J = 13.4 and 4.8 Hz, 1H), 2.99 (dd, J = 12.9 and 12.9 Hz, 1H), 2.51 (m, 1H), 2.37 (s, 3H), 2.36 (m, 1H), 2.09 (m, 1H), 1.38-1.26 (m, 2H) ppm. ¹³C NMR (101 MHz, CDCl₃) δ 143.5, 138.2, 137.3, 135.0, 129.6, 127.7, 127.0, 125.2, 125.0, 124.8, 124.7, 124.4, 52.0, 40.6, 31.5, 29.4, 21.5 ppm. HRMS (APCI+, m/z): calculated for C₁₉H₂₀NO₂S [M+H⁺]: 326.1215, found: 326.1210.

The title compound was prepared from 5d (0.26 mmol, 55 mg) in toluene (26 mL) following general procedure C. Purification by column chromatography (SiO₂, EtOAc/Pentane 1:99, Rₖ = 0.7) afforded 9 (95% yield, 46 mg, 95% ee, [α]₀⁺²⁰ = +124.8 (c 1.0 in CHCl₃)) as a colorless oil. Enantiomeric excess determined by chiral GC analysis, Chiraldex B-PM column (30 m x 0.25 mm), 5 min isothermic 50 °C then 2 °C/min gradient to 175 °C, retention times (min) 66.2 (major) and 67.0 (minor). ¹H NMR (400 MHz, CDCl₃) δ 7.49 (dd, J = 7.9 and 1.6 Hz, 1H), 7.13-7.09 (m, 1H), 6.90-6.86 (m, 1H), 6.83 (dd, J = 8.2 and 1.1 Hz, 1H), 6.25 (m, 1H), 4.28 (dd, J = 10.4 and 4.6 Hz, 1H), 3.66 (dd, J = 12.0 and 10.4 Hz, 1H), 2.67 (m, 1H), 2.27 (m, 2H), 1.89 (m, 2H), 1.64 (m, 1H), 1.13 (m, 1H) ppm. ¹³C NMR (101 MHz, CDCl₃) δ 154.1, 131.0, 128.2, 123.6, 121.7, 120.6, 118.6, 117.2, 71.3, 33.7, 25.9, 24.8, 21.4 ppm. HRMS (APCI+, m/z): calculated for C₁₃H₁₅O [M+H⁺]: 187.1123, found: 187.1121.

Stereoselective hydroboration-oxidation

1) S-BEEN/THF
2) EIOH/H₂O₂
NaOH
((+)-3-methylchroman-4-yl)methanol (10)

In an oven dried Schlenk tube equipped with septum and stirring bar under a N₂ atmosphere, chromene 5a (0.28 mmol, 45 mg) was dissolved in anhydrous THF (0.5 mL), cooled to 0 °C and 9-BBN-THF (0.5M solution in THF, 0.42 mmol, 840 µL) was then added dropwise. The reaction mixture was stirred for 3 h, then it was allowed to reach rt, after which sequentially EtOH (2.5 mL), aq. NaOH (1M, 2.5 mL) and aq H₂O₂ (30%, 2.0 mL) were added. The resulting mixture was stirred overnight at rt and then quenched with aq Na₂S₂O₃ (10%, 10 mL). CH₂Cl₂ (20 mL) was added, the layers were separated and the aqueous layer was extracted with CH₂Cl₂ (20 mL). The combined organic layers were dried and concentrated in vacuo. Flash column chromatography (SiO₂, EtOAc/Pentane 3:7, R_f = 0.6) afforded 10 (81% yield, 40 mg, [α]_D^{20} = +79.0 (c 1.3 in CHCl₃)) as a colorless oil. ¹H NMR (400 MHz, CDCl₃) δ 7.18-7.12 (m, 2H), 6.89-6.82 (m, 2H), 4.12-4.02 (m, 2H), 3.97-3.88 (m, 2H), 2.93 (m, 1H), 2.39-2.29 (m, 1H), 1.10 (d, J = 7.1 Hz, 3H) ppm. ¹³C NMR (101 MHz, CDCl₃) δ 154.7, 129.3, 128.0, 122.4, 120.2, 116.8, 69.7, 63.7, 40.7, 29.2, 13.0 ppm. HRMS (APCI+, m/z): calculated for C₁₁H₁₅O₂ [M+H⁺]: 179.1072, found: 179.1067.

Stereoselective hydrogenation

(+)-3-hexyl-4-methylchroman (11)

To an oven-dried flask was added RhCl(PPh₃)₃ (20 mg, 0.02 mmol) and a solution of 5e (20 mg, 0.09 mmol) in benzene (2 mL). The flask was connected to a hydrogen balloon. After five vacuum/H₂-filling cycles, the reaction mixture was stirred at rt for 15 h. The resulting mixture was concentrated under reduced pressure. The residue was purified by flash column chromatography (SiO₂, EtOAc/Pentane 1:99, R_f = 0.7) afforded 11a (96% yield, 20 mg, 9:1 d.r., [α]_D^{20} = +47.2 (c 1.0 in CHCl₃)) as a colorless oil. ¹H NMR (400 MHz, CDCl₃) δ 7.14-7.07 (m, 2H), 6.89-6.77 (m, 2H), 4.17 (dd, J = 11.0 and 2.7 Hz, 1H, minor (anti)), 4.07 (ddd, J = 10.8, 3.6 and 1.2 Hz, 1H, major (syn)), 3.92 (dd, J = 10.6 and 10.6 Hz, 1H), 2.92 (m, 1H, major (syn)).
(+)-4-methyl-3-pentyl-1-tosyl-1,2,3,4-tetrahydroquinoline (12)

Compound prepared from 6d (60 mg, 0.16 mmol) in benzene (2 mL) and RhCl(PPh3)3 (38 mg, 0.040 mmol) following the procedure described for 11a. Purification by flash column chromatography (SiO2, EtOAc/Pentane 10:90, Rf = 0.7) afforded 12 (98% yield, 58 mg, 10:1 d.r., [α]D20 = +62.0 (c 1.1 in CHCl3)) as a colorless oil. 1H NMR (400 MHz, CDCl3) δ 7.91 (d, J = 8.3 Hz, 1H), 7.50 (m, 2H), 7.20-7.14 (m, 3H), 7.03-7.01 (m, 2H), 4.13 (dd, J = 13.6 and 4.1 Hz, 1H, minor (anti)), 3.97 (ddd, J = 12.1, 12.1 Hz, 1H, major (syn)), 3.15 (dd, J = 13.6, 10.2 Hz, 1H, minor (anti)), 2.64 (m, 1H), 2.35 (s, 3H), 1.65 (m, 1H), 1.32-1.19 (m, 8H), 0.88 (t, J = 7.1 Hz, 3H), 0.87 (d, 3H, J = 6.9 Hz, minor (anti)), 0.72 (d, J = 7.2 Hz, 3H, major (syn)) ppm. 13C NMR (101 MHz, CDCl3) δ 143.5, 135.9, 135.7, 135.5, 129.5, 128.9, 127.1, 126.6, 124.1, 122.9, 47.3, 35.5, 35.0, 31.8, 29.9, 26.6, 22.5, 21.5, 15.8, 14.0 ppm. HRMS (APCI+, m/z): calculated for C22H30NO2S [M+H+]: 372.1997, found: 372.1992.
NMR spectra

(E)-2-(4-Bromobut-2-enyloxy)-1-bromobenzene (1)
(+)-1-Bromo-2-(2-methylbut-3-enyloxy)benzene (3a)
(+)-1-bromo-2-(2-ethylbut-3-enyloxy)benzene (3b)
(+)-1-bromo-2-(2-vinylhex-5-enyloxy)benzene (3c)

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(+)-1-bromo-2-(2-vinylhept-6-enyloxy)benzene (3d)
(+)-1-bromo-2-(2-vinylcyclooct-7-enyloxy)benzene (3e)
(+)-N-(2-bromophenyl)-N-(2-ethylbut-3-enyl)-4-methylbenzenesulfonamide (4b)
(+)-N-(2-bromophenyl)-4-methyl-N-(2-vinylhex-5-enyl)benzenesulfonamide (4c)
(+)-N-(2-bromophenyl)-4-methyl-N-(2-vinylhept-6-enyl)benzenesulfonamide (4d)
(+)-N-(2-bromophenyl)-4-methyl-N-(2-vinyloct-7-enyl)benzenesulfonamide (4e)
(+)-3-methyl-4-methylenechromene (5a)
(-)-3-ethyl-4-methylenechromene (5b)
(+)-3-(but-3-enyl)-4-methylenechromene (5c)
(-)-4-methylene-3-(pent-4-enyl)chromene (5d)
(-)-3-(hex-5-enyl)-4-methylenechromene (5e)
(+)-3-methyl-4-methylene-1-tosyl-1,2,3,4-tetrahydroquinoline (6a)
(-)-3-ethyl-4-methylene-1-tosyl-1,2,3,4-tetrahydroquinoline (6b)
(-)-3-(but-3-enyl)-4-methylene-1-tosyl-1,2,3,4-tetrahydroquinoline (6c)
(-)-4-methylene-3-(pent-4-enyl)-1-tosyl-1,2,3,4-tetrahydroquinoline (6d)
(+)-3-(hex-5-enyl)-4-methylene-1-tosyl-1,2,3,4-tetrahydroquinoline (6e)
(+)-2,3,3a,4-tetrahydrocyclopenta[c]chromene (7)
(+)-5-tosyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline (8)
(+)-6a,7,8,9-tetrahydro-6H-benzo[c]chromene (9)
((+)-3-methylchroman-4-yl)methanol (10)
(+)-3-hexyl-4-methylchromane (11)
(+)-4-methyl-3-pentyl-1-tosyl-1,2,3,4-tetrahydroquinoline (12)
Selected IR spectra

Chromene 5e

Tetrahydroquinoline 6c