A Formal [4+2] Cycloaddition of Sulfur-Containing Alkylidene Heterocycles with Allenic Compounds

Vojtěch Dočekal§[a], Bedřich Formánek§[a], Ivana Císařová[b] and Jan Veselý*[a]

[a] Department of Organic Chemistry, Faculty of Science, Charles University, Hlavova 2030/8, 128 43 Prague 2
[b] Department of Inorganic Chemistry, Faculty of Science, Charles University, Hlavova 2030/8, 128 43 Prague 2
§ These authors contributed equally to this work.

Electronic Supplementary Information
# Table of Contents

Table of Contents ......................................................................................................................... S2

General ............................................................................................................................................. S3

Optimization of reaction conditions for cycloaddition reaction ................................................. S4

Starting material .............................................................................................................................. S9
  Preparation of allenoates and selected alkylidenes ................................................................. S9
  Preparation of benzothiophen-2-ones ....................................................................................... S9
  Preparation of 3-alkylidenebenzothiophenones ..................................................................... S11

General procedure for formal cycloaddition reaction ............................................................... S18

Further transformations .................................................................................................................. S29

Crystallographic data for 3a and 6b ............................................................................................ S32

NMR spectra ................................................................................................................................. S35

Chiral HPLC ................................................................................................................................. S90
General

Chemicals and solvents were either purchased puriss p.A. from commercial suppliers or purified by standard techniques. For thin-layer chromatography (TLC), silica gel plates Merck 60 F254 were used and compounds were visualized by irradiation with UV light and/or by treatment with a solution of phosphomolybdic acid (AMC) or vaniline followed by heating. The solution of AMC was prepared from phosphomolybdic acid (25 g), Ce(SO₄)₂ · H₂O (10 g), conc. H₂SO₄ (60 ml) and H₂O (940 ml). The solution of vaniline was prepared from vaniline (15 g) in ethanol (250 ml) and conc. sulfuric acid (2.5 ml). Column chromatography was performed using silica gel Fluka (40-63 µm). ¹H, ¹⁹F and ¹³C NMR spectra were recorded with Bruker AVANCE III 400. Chemical shifts for protons are given in δ and are referenced to residual protium in the NMR solvent (Chloroform-d: δ = 7.26 ppm). Chemical shifts for carbon are referenced to the carbon in NMR solvent (Chloroform-d: δ = 77.0 ppm). The coupling constants J are given in Hz. Chiral HPLC was carried out using a LC20AD Shimadzu liquid chromatograph with SPD-M20A diode array detector with columns Daicel Chiralpak® IA, Daicel Chiralpak® IB, Daicel Chiralpak® AD, Daicel Chiralpak® ODH. Optical rotations were measured on AU-Tomatica polarimeter, Autopol III. Specific optical rotations are given in concentrations c [g/100 ml]. IR DRIFT spectras were recorded with Nicolet AVATAR 370 FT-IR in cm⁻¹. High-resolution mass spectras were recorded with a LCQ Fleet spectrometer.
Optimization of reaction conditions for cycloaddition reaction

Table S1. Catalyst screening.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Catalyst</th>
<th>Time (h)</th>
<th>Conver.s (a) (%)</th>
<th>3a/4a (a)</th>
<th>Yield (b) (%)</th>
<th>ee (c) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>none</td>
<td>120</td>
<td>0</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>2</td>
<td>2,4-DNBA</td>
<td>120</td>
<td>0</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>3</td>
<td>DABCO</td>
<td>15</td>
<td>100</td>
<td>7:1</td>
<td>98</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>PPh₃</td>
<td>120</td>
<td>70</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>5</td>
<td>β-ICD</td>
<td>15</td>
<td>100</td>
<td>&gt;20:1</td>
<td>94</td>
<td>48</td>
</tr>
<tr>
<td>6</td>
<td>QN</td>
<td>15°</td>
<td>84</td>
<td>&gt;20:1</td>
<td>49</td>
<td>-64</td>
</tr>
<tr>
<td>7</td>
<td>QD</td>
<td>15</td>
<td>100</td>
<td>20:1</td>
<td>83</td>
<td>73</td>
</tr>
<tr>
<td>8</td>
<td>QD</td>
<td>40</td>
<td>100</td>
<td>20:1</td>
<td>70</td>
<td>71</td>
</tr>
<tr>
<td>9</td>
<td>QD</td>
<td>48</td>
<td>89</td>
<td>20:1</td>
<td>67</td>
<td>-16</td>
</tr>
<tr>
<td>10</td>
<td>CN</td>
<td>65</td>
<td>76</td>
<td>15:1</td>
<td>72</td>
<td>39</td>
</tr>
<tr>
<td>11</td>
<td>TMS-QD</td>
<td>15</td>
<td>100</td>
<td>&gt;20:1</td>
<td>91</td>
<td>66</td>
</tr>
<tr>
<td>12</td>
<td>Bz-QD</td>
<td>18</td>
<td>55</td>
<td>20:1</td>
<td>52</td>
<td>52</td>
</tr>
<tr>
<td>13</td>
<td>(DHQD)₂AQN</td>
<td>15°</td>
<td>100</td>
<td>&gt;20:1</td>
<td>83</td>
<td>63</td>
</tr>
<tr>
<td>14</td>
<td>(DHQ)₂AQN</td>
<td>15</td>
<td>100</td>
<td>20:1</td>
<td>83</td>
<td>-53</td>
</tr>
<tr>
<td>15</td>
<td>(DHQD)₂Phal</td>
<td>65</td>
<td>73</td>
<td>8:1</td>
<td>47</td>
<td>64</td>
</tr>
<tr>
<td>16</td>
<td>(DHQ)₂Phal</td>
<td>48</td>
<td>70</td>
<td>20:1</td>
<td>39</td>
<td>-5</td>
</tr>
<tr>
<td>17</td>
<td>(DHQD)₂Pyr</td>
<td>15</td>
<td>90</td>
<td>11:1</td>
<td>43</td>
<td>71</td>
</tr>
<tr>
<td>18</td>
<td>(DHQ)₂Pyr</td>
<td>15</td>
<td>100</td>
<td>20:1</td>
<td>86</td>
<td>-68</td>
</tr>
<tr>
<td>19</td>
<td>C₁</td>
<td>120</td>
<td>0</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>20</td>
<td>C₂</td>
<td>120</td>
<td>0</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>21</td>
<td>(R,R)-TUC</td>
<td>120</td>
<td>0</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
</tbody>
</table>

(a) Determined by ¹H NMR of crude reaction mixture. (b) Isolated yield after column chromatography. (c) Determined by HPLC with IB chiral column. [d] Different product was observed. [e] Reaction was performed at -20 °C. 2,4-DNBA = 2,4-dinitrobenzoic acid
Figure S1. Structures of catalysts screened.
Table S2. Solvent screening.

- **Diagram**: Chemical reaction showing the formation of compounds 3a and 4a with solvents 1a and 2a, respectively.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Solvent</th>
<th>Time (h)</th>
<th>Conversion[a] (%)</th>
<th>3a/4a[a]</th>
<th>Yield[b] (%)</th>
<th>ee (%)[c]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CHCl₃</td>
<td>15</td>
<td>100</td>
<td>20:1</td>
<td>83</td>
<td>73</td>
</tr>
<tr>
<td>2</td>
<td>DCM</td>
<td>15</td>
<td>100</td>
<td>19:1</td>
<td>86</td>
<td>78</td>
</tr>
<tr>
<td>3</td>
<td>DCE</td>
<td>15</td>
<td>90</td>
<td>17:1</td>
<td>73</td>
<td>82</td>
</tr>
<tr>
<td>4</td>
<td>MTBE</td>
<td>15</td>
<td>95</td>
<td>19:1</td>
<td>98[d]</td>
<td>74</td>
</tr>
<tr>
<td>5</td>
<td>THF</td>
<td>15</td>
<td>100</td>
<td>19:1</td>
<td>90</td>
<td>78</td>
</tr>
<tr>
<td>6</td>
<td>EtOAc</td>
<td>15</td>
<td>100</td>
<td>12:1</td>
<td>93</td>
<td>83</td>
</tr>
<tr>
<td>7</td>
<td>MeCN</td>
<td>15</td>
<td>91</td>
<td>12:1</td>
<td>72</td>
<td>85</td>
</tr>
<tr>
<td>8</td>
<td>acetone</td>
<td>15</td>
<td>100</td>
<td>9:1</td>
<td>80</td>
<td>86</td>
</tr>
<tr>
<td>9</td>
<td>benzene</td>
<td>15</td>
<td>100</td>
<td>20:1</td>
<td>93</td>
<td>79</td>
</tr>
<tr>
<td>10</td>
<td>toluene</td>
<td>40</td>
<td>90</td>
<td>&gt;20:1</td>
<td>95</td>
<td>75</td>
</tr>
<tr>
<td>11</td>
<td>DMF</td>
<td>15</td>
<td>100</td>
<td>4:1</td>
<td>62</td>
<td>86</td>
</tr>
<tr>
<td>12</td>
<td>DMSO</td>
<td>15</td>
<td>100</td>
<td>5:1</td>
<td>41</td>
<td>73</td>
</tr>
<tr>
<td>13</td>
<td>MeOH</td>
<td>15</td>
<td>100</td>
<td>&gt;20:1</td>
<td>82[d]</td>
<td>89</td>
</tr>
<tr>
<td>14</td>
<td>EIOH</td>
<td>15</td>
<td>100</td>
<td>&gt;20:1</td>
<td>75[d]</td>
<td>83</td>
</tr>
<tr>
<td>15</td>
<td>2,2,2-trifluoroethanol</td>
<td>120</td>
<td>50</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>16</td>
<td>i-PrOH</td>
<td>15</td>
<td>100</td>
<td>&gt;20:1</td>
<td>77[d]</td>
<td>67</td>
</tr>
<tr>
<td>17</td>
<td>PrOH</td>
<td>15</td>
<td>100</td>
<td>&gt;20:1</td>
<td>79[d]</td>
<td>80</td>
</tr>
<tr>
<td>18</td>
<td>Diethylene glycol</td>
<td>15</td>
<td>95</td>
<td>7:1</td>
<td>71[d]</td>
<td>85</td>
</tr>
</tbody>
</table>

[a] Determined by ¹H NMR of crude reaction mixture. [b] Isolated yield after column chromatography. [c] Determined by HPLC with IB chiral column. [d] Product precipitated from reaction mixture.
Table S3. Additive screening.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Additive</th>
<th>Time (h)</th>
<th>Convers.(^{[a]}) (%)</th>
<th>3a/4a(^{[a]})</th>
<th>Yield(^{[b]}) (%)</th>
<th>ee (%)(^{[c]})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>none</td>
<td>15</td>
<td>100</td>
<td>&gt;20:1</td>
<td>82(^{[d]})</td>
<td>89</td>
</tr>
<tr>
<td>2</td>
<td>PhCOOH</td>
<td>15</td>
<td>90</td>
<td>&gt;20:1</td>
<td>77(^{[d]})</td>
<td>89</td>
</tr>
<tr>
<td>3</td>
<td>p-TsOH</td>
<td>15</td>
<td>92</td>
<td>&gt;20:1</td>
<td>78(^{[d]})</td>
<td>84</td>
</tr>
<tr>
<td>4</td>
<td>2,4-DNBA</td>
<td>15</td>
<td>97</td>
<td>&gt;20:1</td>
<td>92(^{[d]})</td>
<td>90</td>
</tr>
<tr>
<td>5</td>
<td>PhOH</td>
<td>15</td>
<td>100</td>
<td>17:1</td>
<td>75</td>
<td>85</td>
</tr>
<tr>
<td>6</td>
<td>4-NO(_2)PhOH</td>
<td>15</td>
<td>95</td>
<td>19:1</td>
<td>89(^{[d]})</td>
<td>89.5</td>
</tr>
<tr>
<td>7</td>
<td>(S)-CSA</td>
<td>15</td>
<td>94</td>
<td>&gt;20:1</td>
<td>77(^{[d]})</td>
<td>84</td>
</tr>
<tr>
<td>8</td>
<td>(R)-BNPPA</td>
<td>15</td>
<td>100</td>
<td>19:1</td>
<td>71(^{[d]})</td>
<td>88</td>
</tr>
<tr>
<td>9</td>
<td>2,4-DNBA</td>
<td>20</td>
<td>87</td>
<td>&gt;20:1</td>
<td>88</td>
<td>74</td>
</tr>
</tbody>
</table>

\(^{[a]}\) Determined by \(^1\)H NMR of crude reaction mixture. \(^{[b]}\) Isolated yield after column chromatography. \(^{[c]}\) Determined by HPLC with IB chiral column. \(^{[d]}\) Product precipitated from reaction mixture. (S)-CSA = (1S)-(+)-Camphorsulfonic acid, (R)-BNPPA = (R)-(-)-1,1'-Binaphthyl-2,2'-diyl hydrogenphosphate

Table S4. Temperature screening.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Temperature</th>
<th>Time (h)</th>
<th>Convers.(^{[a]}) (%)</th>
<th>3a/4a(^{[a]})</th>
<th>Yield(^{[b]}) (%)</th>
<th>ee (%)(^{[c]})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>r.t.</td>
<td>15</td>
<td>100</td>
<td>&gt;20:1</td>
<td>92(^{[d]})</td>
<td>90</td>
</tr>
<tr>
<td>2</td>
<td>0 °C</td>
<td>72</td>
<td>96</td>
<td>19:1</td>
<td>75(^{[d]})</td>
<td>88</td>
</tr>
<tr>
<td>3</td>
<td>-20 °C</td>
<td>120</td>
<td>62</td>
<td>8:1</td>
<td>55(^{[d]})</td>
<td>85</td>
</tr>
<tr>
<td>4</td>
<td>40 °C</td>
<td>5</td>
<td>85</td>
<td>20:1</td>
<td>90(^{[d]})</td>
<td>86</td>
</tr>
<tr>
<td>5</td>
<td>60 °C</td>
<td>5</td>
<td>85</td>
<td>5:1</td>
<td>56</td>
<td>66</td>
</tr>
</tbody>
</table>

\(^{[a]}\) Determined by \(^1\)H NMR of crude reaction mixture. \(^{[b]}\) Isolated yield after column chromatography. \(^{[c]}\) Determined by HPLC with IB chiral column. \(^{[d]}\) Product precipitated from reaction mixture.
Table S5. Concentration screening.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Concentration</th>
<th>Time (h)</th>
<th>Convers.[a] (%)</th>
<th>3a/4a[b]</th>
<th>Yield[b] (%)</th>
<th>ee (%)[c]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.2 mol/l</td>
<td>15</td>
<td>100</td>
<td>&gt;20:1</td>
<td>92[d]</td>
<td>90</td>
</tr>
<tr>
<td>2</td>
<td>0.1 mol/l</td>
<td>15</td>
<td>92</td>
<td>20:1</td>
<td>78[d]</td>
<td>89</td>
</tr>
<tr>
<td>3</td>
<td>0.05 mol/l</td>
<td>48</td>
<td>87</td>
<td>10:1</td>
<td>69</td>
<td>90</td>
</tr>
<tr>
<td>4</td>
<td>0.4 mol/l</td>
<td>15</td>
<td>100</td>
<td>&gt;20:1</td>
<td>86[d]</td>
<td>86</td>
</tr>
<tr>
<td>5</td>
<td>0.8 mol/l</td>
<td>15</td>
<td>100</td>
<td>20:1</td>
<td>93[d]</td>
<td>88</td>
</tr>
</tbody>
</table>

[a] Determined by $^1$H NMR of crude reaction mixture. [b] Isolated yield after column chromatography. [c] Determined by HPLC with IB chiral column. [d] Product precipitated from reaction mixture.

Table S6. Catalyst and additive loading screening.

<table>
<thead>
<tr>
<th>Entry</th>
<th>A</th>
<th>B</th>
<th>Time (h)</th>
<th>Convers.[a] (%)</th>
<th>3a/4a[b]</th>
<th>Yield[b] (%)</th>
<th>ee (%)[c]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>10</td>
<td>15</td>
<td>97</td>
<td>&gt;20:1</td>
<td>92[d]</td>
<td>90</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>20</td>
<td>48</td>
<td>89</td>
<td>&gt;20:1</td>
<td>75[d]</td>
<td>89</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>50</td>
<td>120</td>
<td>0</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>100</td>
<td>120</td>
<td>100</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>5</td>
<td>40</td>
<td>98</td>
<td>&gt;20:1</td>
<td>90[d]</td>
<td>84</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>2.5</td>
<td>72</td>
<td>92</td>
<td>&gt;20:1</td>
<td>75[d]</td>
<td>86</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>0</td>
<td>15</td>
<td>100</td>
<td>&gt;20:1</td>
<td>72[d]</td>
<td>82</td>
</tr>
</tbody>
</table>

[a] Determined by $^1$H NMR of crude reaction mixture. [b] Isolated yield after column chromatography. [c] Determined by HPLC with IB chiral column. [d] Product precipitated from reaction mixture.
Starting material

Preparation of allenoates and selected alkylidenes

Allenoates 2a and 2b were prepared according to previously reported procedures.\(^1\) Corresponding allenic ketone 2c was prepared according to previously reported procedure.\(^2\) \((Z)\)-2-benzylidenebenzo[b]thiophen-3(2H)-one (5a) was prepared by Wittig reaction from thioisatine.\(^3\) Thiazolone alkylidene 5b was prepared according to previously reported procedure.\(^4\) Thiazolone alkylidene 5c was prepared according to previously reported procedure.\(^5\)

Preparation of benzothiophen-2-ones

To a stirred solution of 2,2,6,6-tetramethylpiperidine (0.52 ml, 3.05 mmol, 1.3 eq.) in anhydrous THF (3 ml) was n-BuLi (1.13 ml, 2.81 mmol, 1.2 eq., 2.5M solution in hexanes) added dropwise (during 3 minutes) at -78 °C under argon atmosphere. Reaction was stirred for 15 min at the same temperature. Light yellow solution was slowly cannulated to a stirred solution of corresponding thiophene 10 (2.34 mmol, 1.0 eq.) in anhydrous THF (7 ml) under Ar atmosphere. Resulting reaction mixture was stirred at the same temperature for 1.5 h. Then triisopropyl borate (0.87 ml, 3.74 mmol, 1.6 eq.) was added dropwise. Reaction mixture was stirred for 30 min at -78 °C, then 1 h at room temperature. Reaction was quenched with HCl (10 ml, 1M). Resulting suspension was stirred for 15 min at room temperature. Mixture was diluted with Et\(_2\)O (30 ml). Organic phase was separated and water phase was washed with Et\(_2\)O (2 × 30 ml). Collected organic phases were washed with solution of NaOH (2 × 25 ml, 1M). Collected alkaline solutions were neutralized and acidified to pH ~ 2 with hydrochloric acid (36%). Resulting suspension was washed with Et\(_2\)O (3 × 30 ml). Collected org. phases were extracted with brine (1 × 20 ml) and dried under anhydrous MgSO\(_4\). Mixture was filtered and solvents were evaporated in vacuo to give crude boronic acid, which was used directly in next step.

Following the reported procedure,\(^6\) to a solution of crude boronic acid (2.3 mmol) in EtOH (4.0 ml) was H\(_2\)O\(_2\) (30%, 1.0 eq.) added dropwise. Reaction was stirred overnight at room temperature. Then solvent was carefully evaporated on rotavap. Residue was suspended in water (20 ml). This mixture was washed with EtOAc (3 × 30 ml). Collected organic phases were washed with brine (1 × 30 ml) and dried under anhydrous MgSO\(_4\). Mixture was filtered and solvents were evaporated in vacuo. Crude product was purified by flash chromatography (Hex/EtOAc) affording desired products.

---

Benzo[b]thiophen-2(3H)-one (11a)

The title compound was synthesized according to general procedure. Known compound, light brown solid, yield = 95 % (for last step – commercially available boronic acid). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ = 7.38 – 7.15 (m, 4H), 3.96 (s, 2H) ppm.

5-Chlorobenzo[b]thiophen-2(3H)-one (11b)

The title compound was synthesized according to general procedure. White solid, yield = 71 % (over four steps); $m.p.$ = 112.7 °C; $^1$H NMR (400 MHz, Chloroform-d): $\delta$ = 7.33 – 7.26 (m, 3H), 3.97 (s, 2H) ppm; $^{13}$C NMR (101 MHz, Chloroform-d): $\delta$ = 201.7, 135.4, 133.6, 132.1, 128.6, 125.1, 124.0, 47.2 ppm; IR (KBr): $\nu$ = 3428, 3117, 3079, 3022, 2941, 2908, 2095, 2029, 1891, 1853, 1814, 1760, 1700, 1688, 1628, 1592, 1559, 1461, 1443, 1416, 1974, 1275, 1228, 1195, 1132, 1087, 1021, 1006, 911 cm$^{-1}$, HRMS (EI) $m/z$: calcd. for C$_8$H$_6$OSCl [M]: 183.9750, found: 183.9749.

5-Nitrobenzo[b]thiophen-2(3H)-one (11c)

The title compound was synthesized according to general procedure. Light orange solid; yield = 38 % (over four steps); $m.p.$ = 125.4 °C; $^1$H NMR (400 MHz, Chloroform-d): $\delta$ = 8.83 – 8.13 (m, 2H), 7.53 (d, $J$ = 8.4 Hz, 1H), 4.10 (s, 2H) ppm, $^{13}$C NMR (101 MHz, Chloroform-d): $\delta$ = 199.8, 146.4, 145.9, 133.2, 123.8, 123.4, 119.8, 46.9 ppm; IR (KBr): $\nu$ = 3422, 3094, 3073, 3043, 3025, 2989, 2938, 2911, 2848, 2830, 2738, 2627, 2531, 2026, 1927, 1862, 1718, 1688, 1637, 1598, 1574, 1527, 1512, 1464, 1422, 1341, 1311, 1272, 1228, 1198, 1141, 1078, 1039, 1018, 934, 920, 836, 812 cm$^{-1}$; HRMS (EI) $m/z$: calcd. for C$_8$H$_6$NO$_2$S [M]: 194.9990, found: 194.9993.

5-Methylbenzo[b]thiophen-2(3H)-one (11d)

The title compound was synthesized according to general procedure. Known compound, white solid, yield 76% (over four steps), $m.p.$ = 75.6 °C; $^1$H NMR (400 MHz, Chloroform-d): $\delta$ = 7.24-7.20 (m, 2H), 7.17 – 7.06 (m, 2H), 3.93 (s, 2H), 2.34 (s, 3H) ppm.

5-Bromobenzo[b]thiophen-2(3H)-one (11e)

The title compound was synthesized according to general procedure. Light yellow solid, yield = 69 % (over four steps), $m.p.$ = 125.4 °C; $^1$H NMR (400 MHz, Chloroform-d): $\delta$ = 7.52 – 7.37 (m, 2H), 7.26 – 7.20 (m, 1H), 3.98 (s, 2H) ppm, $^{13}$C NMR (101 MHz, Chloroform-d): $\delta$ = 201.5, 136.0, 133.9, 131.4, 127.9, 124.3, 119.7, 47.1 ppm; IR (KBr): $\nu$ = 3419, 3411, 3114, 3073, 2938, 2902, 2152, 2110, 2077, 2038, 1903, 1814, 1715, 1649, 1622, 1556, 1497, 1461, 1440, 1410, 1374, 1281, 1261, 1228, 1195, 1141, 1096, 1018, 824 cm$^{-1}$; HRMS (EI) $m/z$: calcd. for C$_8$H$_6$OSBr [M]: found: 227.9244.

6-Bromobenzo[b]thiophen-2(3H)-one (11f)

The title compound was synthesized according to general procedure. White solid, yield = 65 % (over four steps), $m.p.$ = 90.0 °C, $^1$H NMR (400 MHz, Chloroform-d): $\delta$ = 7.48 (d, $J$ = 1.9 Hz, 1H), 7.34 (dd, $J$ = 8.1, 1.9 Hz, 1H), 7.15 (dt, $J$ = 8.1, 1.2 Hz, 1H), 3.91 (s, 2H) ppm; $^{13}$C NMR (101 MHz, Chloroform-d): $\delta$ = 201.6, 139.0, 130.8, 129.2, 125.9, 125.7, 121.8, 46.7 ppm; IR (KBr): $\nu$ = 3390, 3073, 3061, 2938, 2914, 1885, 1844, 1709, 1664, 1598, 1559, 1518, 1461, 1392, 1362, 1305, 1257,

---

1237, 1189, 1135, 1108, 1090, 1063, 1024, 1003 cm⁻¹; HRMS (EI) m/z: calcd. for C₉H₅OSBr [M]: 227.9244, found: 227.9248.

**7-Bromobenzof[b]thiophen-2(3H)-one (11g)**

The title compound was synthesized according to general procedure. White solid, yield = 71% (over four steps), m.p. = 99.7 °C, ¹H NMR (400 MHz, Chloroform-d): δ = 7.44 (dq, J = 8.1, 1.0 Hz, 1H), 7.22 (dq, J = 7.6, 1.2 Hz, 1H), 7.09 (t, J = 7.8 Hz, 1H), 4.10 (s, 2H) ppm; ¹³C NMR (101 MHz, Chloroform-d): δ = 200.4, 139.5, 133.6, 131.4, 127.3, 123.1, 116.5, 49.3 ppm; IR (KBr): ν = 3405, 3396, 3114, 3061, 3028, 2926, 2902, 2086, 2044, 1945, 1888, 1847, 1808, 1790, 1721, 1712, 1676, 1589, 1553, 1455, 1419, 1380, 1368, 1311, 1269, 1183, 1162, 1141, 1111, 1066, 1024, 979, 887, 770 cm⁻¹; HRMS (EI) m/z: calcd. for C₉H₅OSBr [M]: 227.9244, found: 227.9247.

**4-Bromobenzof[b]thiophen-2(3H)-one (11h)**

The title compound was synthesized according to general procedure. White solid, yield = 83% (over four steps), m.p. = 66.7 °C, ¹H NMR (400 MHz, Chloroform-d): δ = 7.38 (dd, J = 8.1, 1.1 Hz, 1H), 7.28 (dd, J = 7.8, 1.0 Hz, 1H), 7.18 (tt, J = 7.9, 1.0 Hz, 1H), 3.97 (s, 2H) ppm, ¹³C NMR (101 MHz, Chloroform-d): δ = 199.9, 138.2, 132.7, 129.7, 129.5, 121.8, 119.8, 49.4 ppm; IR (KBr): ν = 3415, 3408, 3079, 2926, 2896, 1716, 1670, 1586, 1574, 1556, 1452, 1431, 1377, 1302, 1248, 1219, 1177, 1069, 1027 cm⁻¹, HRMS (EI) m/z: calcd. for C₉H₅OSBr [M]: 227.9244, found: 227.9248.

**Preparation of 3-alkylidenebenzothiophenones**

Following the reported procedure⁸ in a round-bottom flask benzothiophen-2-one 11 (2.0 mmol, 1 eq.) and corresponding aldehyde (2.1 mmol, 1.05 eq.) was dissolved in 96% EtOH (3.5 ml, 0.55M), then piperidine (0.02 ml, 0.2 mmol, 0.1 eq.) was added. Reaction mixture was left to stir overnight at room temperature. After consumption of benzothiophen-2-one (monitored by TLC) the reaction mixture was evaporated and purified by flash column chromatography on silica gel (Hex/EtOAc or Hex/toluene mixtures) or precipitated product was filtered over sintered funnel, washed with small amount of 96% EtOH and recrystallized from boiling 96% EtOH affording desired products.

**3-Benzylidenebenzo[b]thiophen-2(3H)-one (1a)**

The title compound was synthesized according to general procedure. Mixture of E/Z isomers (1a(E)/1a(Z) = 5/1), yellow semi-solid, yield = 78%, pure E isomer 1a(E), yield = 12%; ¹H NMR (400 MHz, Chloroform-d): [isomer 1a(E) − H]: δ = 7.97 − 7.95 (m, 2H), 7.81 (s, 1H), 7.59 − 7.56 (m, 3H, overlapped), 7.49 − 7.43 (m, 3H, overlapped), 7.36 − 7.34 (m, 1H), 7.33 − 7.32 (m, 2H), 7.26 (t, J = 7.7 Hz, 1H, overlapped), 7.02 − 6.98 (m, 1H) ppm; ¹³C NMR (101 MHz, CDCl₃): [isomer 1a(E) − C]: δ = δ 194.6 (1C), 192.2 (1C), 138.7 (1C), 138.4 (1C), 135.9

---

(1C'), 134.9 (1C), 134.3 (1C'), 133.7 (1C'), 133.2 (1C), 133.0 (1C), 131.7 (1C), 131.6 (2C), 131.0 (1C), 130.1 (1C'), 129.9 (1C'), 129.8 (1C'), 129.3 (1C), 128.8 (2C'), 128.8 (2C'), 128.1 (2C), 125.8 (1C), 125.5 (1C'), 124.2 (1C'), 123.5 (1C'), 123.2 (1C), 121.0 (1C) ppm; IR (KBr): v = 3067, 3019, 2657, 2110, 1951, 1918, 1888, 1811, 1778, 1754, 1688, 1667, 1604, 1497, 1443, 1368, 1275, 1222, 1210, 1180, 1075, 1054, 1024, 1003, 937, 905, 878, 845, 800, 764, 726, 698, 606, 564 cm⁻¹; HRMS (ESI) m/z calc: calcd for C_{10}H_{15}NaO_{5}\text{+} [M+Na]^+ = 261.0345, found = 261.0346.

3-Benzylidene-5-chlorobenzo[b]thiophen-2(3H)-one (1b)

The title compound was synthesized according to general procedure. Inseparable mixture of E/Z isomers (1b(E)/1b(Z) = 2.2/1), yellow solid, yield = 84 %; m.p. = 71.9 °C; \textsuperscript{1}H NMR (400 MHz, Chloroform-d): [isomer 1b(E) – H'; isomer 1b(Z) – H]: \(\delta = 8.07 – 7.94\) (m, 2H), 7.68 (d, \(J = 2.6\) Hz, 1H'), 7.61 – 7.40 (m, 6H' + 5H, overlapped), 7.33 – 7.20 (m, 2H + 2H', overlapped) ppm; \textsuperscript{13}C NMR (101 MHz, Chloroform-d): [isomer 1b(E) - C'; isomer 1b(Z) - C]: \(\delta = 193.8\) (1C'), 192.1 (1C, from 2D experiments), 140.2 (2C' + 1C, overlapped), 134.2 (1C' + 1C, overlapped), 133.7 (1C') 133.1 (1C), 132.9 (1C), 131.9 (1C' + 1C, overlapped), 131.6 (1C'), 131.5 (1C), 131.4 (1C'), 130.4 (2C), 129.9 (2C), 129.2 (2C'), 128.9 (2C'), 128.8 (2C'), 128.3 (1C'), 124.4 (1C), 124.2 (1C'), 124.2 (1C), 121.2 (1C') ppm; IR (KBr): v = 3363, 3058, 3025, 2995, 1972, 1879, 1694, 1676, 1604, 1583, 1556, 1494, 1446, 1419, 1377, 1326, 1287, 1260, 1242, 1198, 1168, 1090, 1078, 1051, 1030, 1018 cm⁻¹; HRMS (ESI+) m/z: calcd for C_{13}H_{15}FClNaOS [M+Na]^+ : 294.9954, found: 294.9955.

3-Benzylidene-5-nitrobenzo[b]thiophen-2(3H)-one (1c)

The title compound was synthesized according to general procedure. Inseparable mixture of E/Z isomers (1c(E)/1c(Z) = 2.2/1), yellow solid, yield = 63 %; m.p. = 145.9 °C; \textsuperscript{1}H NMR (400 MHz, Chloroform-d): [isomer 1c(E) – H'; isomer 1c(Z) – H]: \(\delta = 8.52\) (d, \(J = 2.3\) Hz, 1H'), 8.46 (d, \(J = 2.2\) Hz, 1H), 8.21 (dd, \(J = 8.6, 2.2\) Hz, 1H), 8.15 (dd, \(J = 8.6, 2.3\) Hz, 1H'), 8.08 – 8.03 (m, 2H, overlapped), 8.01 (s, 1H'), 7.79 (s, 1H), 7.63 – 7.44 (m, 6H' + 4H, overlapped) ppm; \textsuperscript{13}C NMR (101 MHz, Chloroform-d): [isomer 1c(E) - C'; isomer 1c(Z) - C]: \(\delta = 192.3\) (1C'), 190.0 (1C, from 2D experiments), 146.0 (1C), 140.0 (1C'), 142.9 (1C), 142.5 (2C', overlapped), 134.2 (1C), 133.0 (1C'), 132.4 (1C' + 2C, overlapped), 131.9 (1C'), 131.2 (2C), 130.8 (1C'), 129.3 (2C'), 129.0 (2C), 128.9 (2C), 128.5 (1C), 124.4 (1C'), 123.7 (1C' + 1C, overlapped), 123.6 (1C), 118.8 (1C'), 115.9 (1C) ppm; IR (KBr): v = 3405, 3108, 3085, 3058, 2935, 2914, 2851, 1969, 1915, 1793, 1715, 1679, 1604, 1574, 1521, 1491, 1449, 1338, 1263, 1242, 1263, 1242, 1189, 1171, 1138, 110S, 1084, 1060, 1036, 1018, 1000 cm⁻¹; HRMS (ESI+) m/z: calcd. for C_{13}H_{15}NNaO_{3}S [M+Na]^+ : 306.0196, found: 306.0195.

3-Benzylidene-5-methylbenzo[b]thiophen-2(3H)-one (1d)

The title compound was synthesized according to general procedure. Inseparable mixture of E/Z isomers (1d(E)/1d(Z) = 2.8/1), orange oil, yield = 74 %; \textsuperscript{1}H-NMR (400 MHz, Chloroform-d): [isomer 1d(E) – H'; isomer 1d(Z) – H]: \(\delta = 7.99 – 7.94\) (m, 2H), 7.78 (s, 1H'), 7.64 – 7.38 (m, 7H + 7H', overlapped), 7.23 (t, \(J = 8.4\) Hz, 1H'), 7.15 (ddd, \(J = 7.9, 1.6, 0.7\) Hz, 1H), 7.09 (ddd, \(J = 8.0, 1.8, 0.9\) Hz, 1H'), 2.41 (s, 3H), 2.16 (s, 3H') ppm; \textsuperscript{13}C NMR (101 MHz, Chloroform-d): [isomer 1d(E) – C'; isomer 1d(Z) – C]: \(\delta = 195.2\) (1C'), 192.7 (1C, from 2D experiments), 138.3 (1C), 138.1 (2C'), 135.3 (2C), 134.4 (1C'), 133.9 (1C), 133.3 (1C'), 132.4 (1C'), 131.6 (2C), 130.9 (2C' + 1C, overlapped), 130.3 (2C),...
3-Benzylidene-5-bromobenzo[b]thiophen-2(3H)-one (1e)

The title compound was synthesized according to general procedure. Inseparable mixture of E/Z isomers (1e(E)/1e(Z) = 2.0/1); yellow solid; yield = 82 %; m.p. = 101.6 °C; \( ^1H \) NMR (400 MHz, Chloroform-\( \delta \)):

- Isomer 1e(E) − H\( ^\prime \); isomer 1e(Z) − H\( ^\prime \); \( \delta \) = 8.01 − 7.94 (m, 2H), 7.86 (s, 1H\( ^\prime \)), 7.73 (d, \( J = 2.0 \) Hz, 1H\( ^\prime \)), 7.71 (s, 1H), 7.60 − 7.33 (m, \( 6H + 5H, overlapped \)), 7.25 − 7.15 (m, 1H + 1H, overlapped) ppm; \( ^{13}C \) NMR (101 MHz, Chloroform-\( \delta \)):

  - Isomer 1e(E) − C\( ^\prime \); isomer 1e(Z) − C\( ^\prime \); \( \delta \) = 193.6 (1C\( ^\prime \)), 192.3 (1C, only from 2D), 140.2 (2C\( ^\prime \) + 1C, overlapped), 134.8 (1C\( ^\prime \) + 1C, overlapped), 133.6 (1C\( ^\prime \)), 132.7 (1C\( ^\prime \)), 132.6 (1C\( ^\prime \)), 131.9 (1C\( ^\prime \)), 131.8 (1C\( ^\prime \)), 131.6 (1C\( ^\prime \)), 130.5 (2C\( ^\prime \)), 129.0 (2C\( ^\prime \)), 128.9 (2C\( ^\prime \) + 1C, overlapped), 128.3 (2C\( ^\prime \)), 127.1 (1C\( ^\prime \)), 124.7 (2C\( ^\prime \)), 124.5 (1C\( ^\prime \)), 124.1 (1C\( ^\prime \)), 119.6 (1C\( ^\prime \)), 119.2 (1C\( ^\prime \)) ppm; IR (KBr): \( \nu \) = 3440, 3366, 3082, 3064, 3049, 3022, 3001, 2929, 1963, 1906, 1891, 1688, 1601, 1574, 1553, 1491, 1449, 1440, 1416, 1353, 1314, 1281, 1263, 1242, 1168, 1078, 1048, 1015 cm\(^{-1}\); HRMS (ESI+) \( m/z \): calcd. for C\(_{15}\)H\(_{15}\)OBrNaOS [M+Na\(^{+}\)]: 338.9445, found: 338.9450.

3-Benzylidene-6-bromobenzo[b]thiophen-2(3H)-one (1f)

The title compound was synthesized according to general procedure. Inseparable mixture of E/Z isomers (1f(E)/1f(Z) = 5.8/1), yellow solid, yield = 94 %; m.p. = 101.6 °C; \( ^1H \) NMR (400 MHz, Chloroform-\( \delta \)):

- Isomer 1f(E) − H\( ^\prime \); isomer 1f(Z) − H\( ^\prime \); \( \delta \) = 8.00 − 7.89 (m, 2H), 7.84 (s, 1H\( ^\prime \)), 7.58 (s, 1H\( ^\prime \)), 7.57 − 7.41 (m, \( 7H + 5H, overlapped \)), 7.38 (dd, \( J = 8.4 \) Hz, 1H\( ^\prime \)), 7.12 (dd, \( J = 8.5 \), \( 2.0 \) Hz, 1H\( ^\prime \)) ppm; \( ^{13}C \) NMR (101 MHz, Chloroform-\( \delta \)):

  - Isomer 1f(E) − C\( ^\prime \); isomer 1f(Z) − C\( ^\prime \); \( \delta \) = 193.49, 139.47, 139.2, 137.8, 134.0, 132.8, 131.7, 131.4, 130.1, 129.0, 128.9, 128.8, 128.7, 128.2, 126.2, 125.9, 125.2, 123.6, 122.1 ppm; IR (KBr): \( \nu \) = 3333, 3079, 3058, 3043, 3022, 2932, 1975, 1957, 1888, 1811, 1700, 1676, 1598, 1494, 1464, 1446, 1401, 1317, 1242, 1198, 1171, 1138, 1093, 1054, 1030, 1009, 997 cm\(^{-1}\); HRMS (ESI+) \( m/z \): calcd. for C\(_{15}\)H\(_{15}\)OBrNaOS [M+Na\(^{+}\)]: 338.9446, found: 338.9445.

3-Benzylidene-7-bromobenzo[b]thiophen-2(3H)-one (1g)

The title compound was synthesized according to general procedure. Inseparable mixture of E/Z isomers (1g(E)/1g(Z) = 4.5/1), yellow solid, yield = 61 %; m.p. = 102.5 °C; \( ^1H \)-NMR (400 MHz, Chloroform-\( \delta \)):

- Isomer 1g(E) − H\( ^\prime \); isomer 1g(Z) − H\( ^\prime \); \( \delta \) = 8.03 − 7.96 (m, 2H), 7.86 (s, 1H\( ^\prime \)), 7.62 − 7.39 (m, \( 7H + 6H, overlapped \)), 7.19 (t, \( J = 7.9 \) Hz, 1H\( ^\prime \)), 6.92 (t, \( J = 8.0 \) Hz, 1H\( ^\prime \)) ppm; \( ^{13}C \)-NMR (101 MHz, Chloroform-\( \delta \)):

  - Isomer 1g(E) − C\( ^\prime \); isomer 1g(Z) − C\( ^\prime \); \( \delta \) = 192.9 (1C\( ^\prime \)), 190.6 (1C, from 2D experiments), 140.7 (2C\( ^\prime \)), 140.4 (2C\( ^\prime \)), 138.3 (1C\( ^\prime \) + 2C, overlapped), 134.7 (1C\( ^\prime \)), 133.8 (1C\( ^\prime \)), 132.6 (1C\( ^\prime \)), 131.9 (2C\( ^\prime \)), 131.8 (1C\( ^\prime \)), 131.5 (1C\( ^\prime \)), 130.1 (2C\( ^\prime \)), 128.9 (4C\( ^\prime \)), 128.3 (2C\( ^\prime \)), 127.0 (1C\( ^\prime \)), 126.7 (1C\( ^\prime \)), 122.5 (1C\( ^\prime \)), 119.3 (1C\( ^\prime \)), 117.3 (1C\( ^\prime \)) ppm; IR (KBr): \( \nu \) = 3082, 3052, 3028, 2956, 2923, 2893, 2872, 1694, 1646, 1604, 1580, 1530, 1500, 1458, 1410, 1377, 1356, 1344, 1305, 1263, 1228, 1195, 1171, 1138, 1108, 1084, 1051, 1024, 982, 964 cm\(^{-1}\); HRMS (ESI+) \( m/z \): calcd. for C\(_{15}\)H\(_{15}\)OBrNaOS [M+Na\(^{+}\)]: 338.9448, found: 338.9445.
3-Benzylidene-4-bromobenzobi[b]thiophen-2(3H)-one

The title compound was not possible to isolate in pure form due to instability on silica gel or Al2O3. During purification on silica gel chromatography decomposition of product to starting benzothiothiophenone was observed.

\[ \text{Benzylidene-4-bromobenzobi[b]thiophen-2(3H)-one} \]

3-(4-Chlorobenzylidene)benzo[b]thiophen-2(3H)-one (1h)

The title compound was synthesized according to general procedure and purified by crystallization.

Mixture of E/Z isomers (1hE/1hZ = 6.5/1), yellow solid, yield = 68 %; m.p. = 121 °C; 1H NMR (400 MHz, Chloroform-d): [isomer 1hE – H]; isomer 1h(Z) – H: δ = 7.91 (d, J = 8.6 Hz, 2H), 7.71 (s, 1H'), 7.56 (d, J = 7.3 Hz, 2H), 7.54 (d, J = 8.1 Hz, 1H'), 7.51 (d, J = 8.6 Hz, 2H'), 7.44 (d, J = 8.3 Hz, 2H'), 7.41 – 7.33 (m, 4H+1H'), 7.28 (t, J = 7.5 Hz, 1H+1H'), 7.02 (t, J = 7.7 Hz, 1H') ppm; 13C NMR (101 MHz, CDCl3): [isomer 1h(E) – C; isomer 1h(Z) – C]: δ = δ 194.4 (1C'), 192.4 (1C), 136.9 (1C), 136.7 (1C'), 136.1 (1C'), 135.8 (1C'), 135.0 (1C), 134.1 (1C'), 132.9 (2C), 132.8 (1C), 132.7 (1C'), 132.2 (1C'), 131.6 (1C), 130.2 (2C'), 130.2 (1C'), 129.8 (1C'), 129.5 (1C), 129.2 (2C'), 128.4 (2C), 125.9 (1C), 125.6 (1C'), 124.2 (1C'), 123.6 (1C'), 123.2 (1C), 121.0 (1C) (one qC is missing) ppm; IR (KBr): ν = 3064, 1688, 1607, 1589, 1491, 1404, 1278, 1171, 1156, 1096, 1072, 1054, 1030, 1015, 920, 830 cm⁻¹; HRMS (ESI) m/z: calcd for C15H8ClNaOS⁺ [M+Na⁺] = 294.9955, found = 294.9952.

4-(2-Oxobenzob[b]thiophen-3(2H)-ylidene)methylbenzonitrile (1i)

The title compound was synthesized according to general procedure and purified by crystallization.

Mixture of E/Z isomers (1iE/1iZ = 25/1) – slow isomerisation in CDCl3 solution occurred, yellow solid, yield = 46 %; m.p. = 163 °C; 1H NMR (400 MHz, Chloroform-d): [isomer 1iE – H'; isomer 1i(Z) – H]: δ = 7.95 (d, J = 8.3 Hz, 2H), 7.78 (d, J = 8.3 Hz, 2H'), 7.73 (s, 1H'), 7.70 (d, J = 8.3 Hz, 2H, overlapped), 7.68 (d, J = 8.0 Hz, 2H'), 7.61 (d, J = 7.7 Hz, 1H), 7.55 (s, 1H), 7.41 – 7.31 (m, 3H+3H', overlapped), 7.04 (td, J = 7.8, 1.2 Hz, 1H') ppm; 13C NMR (101 MHz, Chloroform-d): [determined only isomer 1i(E) – C']: δ = 194.0, 139.3, 134.9, 134.9, 132.7 (2C'), 131.7, 131.3, 130.8, 129.3 (2C), 125.8, 124.4, 123.8, 118.2, 113.1 ppm; IR (KBr): ν = 3357, 3049, 2956, 2226, 1796, 1682, 1613, 1278, 1162, 1057, 1024, 923, 845 cm⁻¹; HRMS (ESI) m/z: calcd for C16H12N2NaOS⁺ [M+Na⁺] = 286.0297, found = 286.0298.

3-(4-(Trifluoromethyl)benzylidene)benzo[b]thiophen-2(3H)-one (1j)

The title compound was synthesized according to general procedure and purified by crystallization.

Mixture of E/Z isomers (1jE/1jZ = 12.5/1), yellow solid, yield = 55 %; m.p. = 118 °C; 1H NMR (600 MHz, Chloroform-d): [isomer 1j(E) – H'; isomer 1j(Z) – H]: δ = 7.96 (d, J = 8.1 Hz, 2H'), 7.76 (s, 1H), 7.73 (d, J = 8.1 Hz, 2H), 7.66 (d, J = 8.0 Hz, 2H), 7.60 (d, J = 7.8 Hz, 1H'), 7.57 (s, 1H'), 7.41 – 7.37 (m, 2H), 7.30 (t, J = 7.6 Hz, 1H), 7.02 (t, J = 7.7 Hz, 1H) ppm. 13C NMR (151 MHz, Chloroform-d): [isomer 1j(E) – C; isomer 1j(Z) – C]: δ = 194.2 (1C'), 192.2 (1C), 138.2 (1C'), 136.5 (1C), 136.3 (1C'), 135.8 (1C), 135.8 (1C'), 135.3 (1C), 135.1 (1C'), 133.7 (1C), 132.2 (1C), 131.8 (q, J = 33.2 Hz, 1C), 131.4 (q, J = 33.2 Hz, 1C'), 131.2 (1C), 130.5 (1C'), 130.1 (1C), 129.5 (1C'), 129.0 (2C+2C', overlapped), 126.1 (1C), 125.9 (q,
3-(4-Nitrobenzylidene)benzo[b]thiophen-2(3H)-one (1k)

The title compound was synthesized according to general procedure and purified by crystallization.

Mixture of E/Z isomers (1kE/E)/1k(Z) = 4/1; orange powder, yield = 88 %; m.p. = 149 °C; 1H NMR (400 MHz, Chloroform-d): [isomer 1kE(E) – H'; isomer 1k(Z) – H]: δ = 8.33 (d, J = 8.7 Hz, 2H'), 8.25 (d, J = 8.9 Hz, 2H), 7.96 (d, J = 8.7 Hz, 2H), 7.73 (s, 1H'), 7.72 (d, J = 8.9 Hz, 2H'), 7.60 (d, J = 7.8 Hz, 1H), 7.57 (s, 1H), 7.39 – 7.30 (m, 3H+3H, overlapped), 7.02 (t, J = 7.7 Hz, 1H') ppm; 13C NMR (151 MHz, Chloroform-d): [isomer 1kE(E) – C'; isomer 1k(Z) – C]: δ = 193.9 (1C'), 192.3 (1C), 148.2 (1C), 148.1 (1C'), 141.3 (1C'), 139.4 (1C), 136.6 (1C'), 135.9 (1C'), 135.6 (1C), 134.8 (1C'), 134.4 (1C'), 134.2 (1C'), 131.8 (1C), 131.6 (2C), 130.9 (1C'), 130.5 (1C), 129.6 (2C'), 129.1 (1C), 126.2 (1C), 125.9 (1C'), 124.5 (1C'), 124.2 (2C'), 123.9 (1C'), 123.5 (1C), 123.2 (2C), 121.6 (1C) ppm; IR (KBr): ν = 3372, 3106, 2839, 2457, 1691, 1592, 1518, 1341, 1296, 1272, 1171, 1111, 1069, 1054, 1018, 920 cm⁻¹; HRMS (ESI) m/z: calcd for C₁₈H₁₅N₂NaO₃S⁺ [M+Na⁺] = 329.0218, found = 329.0217.

3-(4-Methoxybenzylidene)benzo[b]thiophen-2(3H)-one (1I)

The title compound was synthesized according to general procedure and purified by column chromatography.

Mixture of E/Z isomers (1I(E)/1I(Z) = 2.2/1), red-orange oil, yield = 95 %; 1H NMR (400 MHz, Chloroform-d): [isomer 1I(E) – H'; isomer 1I(Z) – H]: δ = 8.11 (d, J = 8.7 Hz, 2H), 7.80 (d, J = 7.0 Hz, 1H), 7.75 (s, 1H), 7.60 (d, J = 8.9 Hz, 2H'), 7.55 (d, J = 7.3 Hz, 1H), 7.52 (s, 1H), 7.36 (d, J = 7.8 Hz, 1H'), 7.33 – 7.23 (m, 3H+1H'), 7.04 (td, J = 7.9, 1.3 Hz, 1H'), 6.98 – 6.94 (m, 2H+2H'), 3.89 (s, 3H'), 3.88 (s, 3H) ppm; 13C NMR (101 MHz, Chloroform-d): [isomer 1I(E) – C'; isomer 1I(Z) – C]: δ = 194.8 (1C'), 192.5 (1C), 162.3 (1C), 161.2 (1C'), 159.0 (1C), 138.9 (1C'), 135.7 (1C'), 134.6 (2C), 134.5 (1C), 133.8 (1C), 132.0 (1C'), 131.3 (2C'), 130.5 (1C'), 129.5 (1C'), 129.3 (1C), 128.5 (1C), 126.3 (1C'), 126.2 (1C), 125.7 (1C), 125.4 (1C'), 123.8 (1C'), 123.4 (1C'), 123.0 (1C), 120.5 (1C), 114.2 (2C'), 113.7 (1C), 55.44 (1C), 55.41 (1C) ppm; IR (KBr): ν = 3064, 2836, 1685, 1601, 1512, 1443, 1260, 1180, 1069, 1054, 1030, 1003, 920 cm⁻¹; HRMS (ESI) m/z: calcd for C₁₈H₁₆NaO₃S⁺ [M+Na⁺] = 306.0195, found = 306.0197.

3-(4-Methylbenzylidene)benzo[b]thiophen-2(3H)-one (1m)

The title compound was synthesized according to general procedure and purified by column chromatography.

Mixture of E/Z isomers (1m(E)/1m(Z) = 4/1), yellow oil, yield = 80 %; 1H NMR (400 MHz, Chloroform-d): [isomer 1m(E) – H'; isomer 1m(Z) – H]: δ = 7.92 (d, J = 8.2 Hz, 2H), 7.79 (s, 1H'), 7.70 (d, J = 8.0 Hz, 1H'), 7.58 – 7.56 (m, 2H), 7.50 (d, J = 8.0 Hz, 2H'), 7.35 (d, J = 7.8 Hz, 1H'), 7.34 – 7.30 (m, 2H), 7.27 – 7.24 (m, 3H+3H'), 7.02 (td, J = 7.9, 1.2 Hz, 1H'), 2.43 (s, 3H'), 2.42 (s, 3H) ppm; 13C NMR (101 MHz, Chloroform-d): [isomer 1m(E) – C'; isomer 1m(Z) – C]: δ = 194.7 (1C'), 192.3 (1C), 142.0 (1C), 140.4 (1C'), 139.1 (1C), 138.9 (1C'), 135.8 (1C'),
134.7 (1C), 133.4 (1C), 133.0 (1C'), 132.0 (2C), 131.3 (1C'), 130.8 (1C), 130.5 (1C), 130.3 (1C'), 129.7 (1C'), 129.5 (2C'), 129.1 (2C'), 128.96 (1C), 128.95 (1C), 125.7 (1C), 125.4 (1C'), 124.1 (1C'), 123.4 (1C'), 123.1 (1C), 120.8 (1C), 21.7 (1C), 21.6 (1C') ppm; IR (KBr): v = 3058, 2923, 1688, 1601, 1446, 1380, 1275, 1186, 1162, 1066, 1054, 1027, 1003, 923, 815 cm⁻¹. HRMS (ESI) m/z: calcd for C₁₀H₁₂NaOS⁺ [M+Na]⁺ = 275.0501, found = 275.0501.

3-(4-Bromobenzylidene)benzo[b]thiophen-2(3H)-one (1n)

The title compound was synthesized according to general procedure and purified by crystallization.

(E) isomer, yellow needles, yield = 69 %; m.p. = 146 °C; ¹H NMR (400 MHz, Chloroform-d): δ = 7.69 (s, 1H), 7.60 (d, J = 8.4 Hz, 2H), 7.54 (d, J = 7.6 Hz, 1H), 7.45 (d, J = 8.0 Hz, 2H), 7.38 – 7.35 (m, 1H), 7.28 (td, J = 7.5, 1.1 Hz, 1H), 7.02 (td, J = 7.9, 1.3 Hz, 1H) ppm; ¹³C NMR (101 MHz, Chloroform-d): δ = 194.4, 136.7, 136.1, 134.1, 132.2 (3C), 130.4 (2C), 130.2, 129.8, 125.6, 124.2, 124.0, 123.6 ppm; IR (KBr): v = 3085, 1685, 1604, 1580, 1491, 1395, 1275, 1168, 1108, 1072, 1012, 920, 827 cm⁻¹; HRMS (ESI) m/z: calcd for C₁₃H₁₀BrNaOS⁺ [M+Na]⁺ = 338.9450, found = 338.9441.

3-(3-Bromobenzylidene)benzo[b]thiophen-2(3H)-one (1o)

The title compound was synthesized according to general procedure and purified by crystallization.

(E) isomer, yellow needles, yield = 48 %; m.p. = 98 °C; ¹H NMR (400 MHz, Chloroform-d): δ = 7.70 (s, 2H, overlapped), 7.57 (dd, J = 8.0, 1.3 Hz, 1H), 7.48 (d, J = 7.8 Hz, 2H), 7.38 – 7.32 (m, 2H), 7.29 (td, J = 7.6, 1.2 Hz, 1H), 7.03 (td, J = 7.9, 1.3 Hz, 1H) ppm; ¹³C NMR (101 MHz, Chloroform-d): δ = 194.3, 136.5, 136.2, 136.0, 134.7, 132.6, 131.4, 130.5, 130.3, 129.6, 127.2, 125.7, 124.4, 123.6, 123.0 ppm; IR (KBr): v = 3061, 1688, 1604, 1556, 1452, 1365, 1269, 1180, 1072, 1054, 1003, 929 cm⁻¹; HRMS (ESI) m/z: calcd for C₁₃H₁₀BrO⁺ [M+H]⁺ = 316.9630, found = 316.9640.

3-(2-Bromobenzylidene)benzo[b]thiophen-2(3H)-one (1p)

The title compound was synthesized according to general procedure and purified by crystallization.

Mixture of E/Z isomers (1p(E)/1p(Z) = 6.5/1), yellow solid, yield = 68 %; m.p. = 121 °C; ¹H NMR (400 MHz, Chloroform-d): [isomer 1p(E) – H'; isomer 1p(Z) – H]: δ = 7.82 (d, J = 7.7 Hz, 1H), 7.74 – 7.71 (m, 2H'), 7.68 (s, 1H), 7.63 (d, J = 8.1 Hz, 2H), 7.54 – 7.52 (m, 1H'), 7.40 – 7.25 (m, 5H+4H', overlapped), 7.21 (d, J = 7.8 Hz, 1H'), 6.97 (t, J = 7.7 Hz, 1H') ppm; ¹³C NMR (101 MHz, Chloroform-d): [isomer 1p(E) – C'; isomer 1p(Z) – C]: δ = 194.0 (1C'), 191.9 (1C), 136.6 (1C'), 136.2 (1C), 136.1 (1C'), 135.2 (1C'), 134.6 (1C), 133.5 (1C), 133.3 (1C'), 132.4 (1C), 131.9 (1C), 131.3 (1C), 130.9 (1C'), 130.3 (1C), 130.2 (1C'), 129.9 (1C'), 129.7 (1C'), 129.6 (1C'), 127.5 (1C'), 126.6 (1C), 126.1 (1C), 125.7 (1C'), 124.7 (1C), 124.5 (1C'), 123.6 (1C'), 123.5 (1C'), 123.3 (1C), 121.6 (1C), (two qC are missing) ppm; IR (KBr): v = 3058, 1691, 1607, 1583, 1446, 1281, 1174, 1135, 1054, 1030, 923, 881 cm⁻¹; HRMS (ESI) m/z: calcd for C₁₉H₁₄BrNaO₂S⁺ [M+Na]⁺ = 370.9712, found = 370.9713.
3-(Furan-3-ylmethylen)benzo[b]thiophen-2(3H)-one (1q)

The title compound was synthesized according to general procedure and purified by column chromatography.

*E* isomer, yellow powder, yield = 41%; m.p. = 103 °C; $^1$H NMR (400 MHz, Chloroform-d): δ = 8.27 (d, J = 3.7 Hz, 1H), 7.67 (d, J = 1.7 Hz, 1H), 7.58 – 7.53 (m, 1H), 7.47 (s, 1H), 7.37 – 7.21 (m, 3H), 6.65 (dd, J = 3.7, 1.2 Hz, 1H) ppm; $^{13}$C NMR (101 MHz, Chloroform-d): δ = 191.9, 151.2, 146.7, 134.8, 132.9, 128.8, 127.1, 125.7, 123.2, 122.8, 120.9, 120.4, 114.0 ppm; IR (KBr): ν = 3357, 3210, 3055, 3016, 2972, 2942, 1942, 1912, 1850, 1772, 1685, 1604, 1586, 1536, 1473, 1449, 1395, 1341, 1302, 1290, 1219, 1159, 1129, 1093, 1048, 1033, 931, 890, 863, 824, 746, 722, 701, 680, 612, 588 cm$^{-1}$; HRMS (ESI) m/z calcld for C_{13}H_{10}O_{5}S $[M+H]^+ = 229.0318$, found = 229.0316.

(E)-3-Butylidenbenzo[b]thiophen-2(3H)-one (1r)

The title compound was synthesized according to general procedure and purified by column chromatography.

*E* isomer, brownish solid, yield = 35%; m.p. = 85.0 °C; $^1$H NMR (400 MHz, Chloroform-d): δ = 7.67 (d, J = 7.6 Hz, 1H), 7.39 – 7.37 (m, 1H), 7.33 – 7.24 (m, 2H), 7.05 (t, J = 7.3 Hz, 1H), 2.67 (q, J = 7.4 Hz, 2H), 1.72 (h, J = 7.4 Hz, 2H), 1.07 (t, J = 7.4 Hz, 3H) ppm; $^{13}$C NMR (101 MHz, Chloroform-d): δ = 194.1, 144.1, 135.5, 134.3, 131.3, 129.0, 126.0, 125.0, 123.5, 31.4, 22.1, 14.0 ppm; IR (KBr): ν = 3058, 2866, 1694, 1625, 1583, 1467, 1446, 1374, 1347, 1293, 1254, 1186, 1132, 1105, 1042, 1024, 914, 851 cm$^{-1}$; HRMS (ESI) m/z calcld for C_{12}H_{12}ONaS$^+$ [M+Na]$^+$ = 227.0501, found = 227.0502.

(E)-3-(Cyclohexylmethylene)benzo[b]thiophen-2(3H)-one (1s)

The title compound was synthesized according to general procedure and purified by column chromatography.

*E* isomer, yellow oil, yield = 33%; $^1$H NMR (400 MHz, Chloroform-d): δ = 7.49 – 7.39 (m, 1H), 7.33 – 7.17 (m, 3H), 6.74 (d, J = 9.8 Hz, 1H), 3.63 (t, J = 11.1, 9.8, 3.5 Hz, 1H), 1.86 – 1.66 (m, 5H), 1.49 – 1.34 (m, 2H), 1.33 – 1.13 (m, 3H) ppm; $^{13}$C NMR (101 MHz, Chloroform-d): δ = 193.5, 149.8, 134.3, 132.0, 131.3, 128.8, 125.7, 123.1, 120.5, 36.3, 32.1, 25.8, 25.4 ppm; IR (KBr): ν = 3933, 3892, 3886, 3874, 3644, 3621, 3616, 3780, 3771, 3760, 3752, 3736, 3726, 3712, 3676, 3650, 3629, 3361, 3297, 3297, 3138, 3063, 3028, 2992, 2925, 2850, 2790, 2656, 2365, 2254, 1938, 1905, 1870, 1830, 1783, 1689, 1614, 1588, 1572, 1550, 1508, 1462, 1449, 1364, 1344, 1314, 1290, 1262, 1239, 1216, 1178, 1160, 1131, 1097, 1071, 1029, 1004, 952, 930, 922, 906, 877, 755, 726, 711, 692, 674, 589 cm$^{-1}$; HRMS (ESI+) m/z: calcld for C_{12}H_{12}ONaS$^+$ [M+Na]$^+$ = 245.0995, found = 245.0995.

(Z)-4-Benzyliden-2-phenylthiazol-5(4H)-one (5c)

Yellow solid, yield = 52%; m.p. = 132 °C, (lit. m. p. = 132°C); $^1$H NMR (400 MHz, Chloroform-d): δ = 8.29 – 8.27 (m, 2H), 8.05 – 8.02 (m, 2H), 7.61 – 7.45 (m, 6H), 7.26 (s, 1H) ppm; $^{13}$C NMR (101 MHz, Chloroform-d): δ = 194.7, 166.8, 146.2, 133.7, 133.4, 133.2 (2C), 132.7, 131.3, 131.3, 129.0 (2C), 128.9 (2C), 128.3 (2C) ppm; IR (KBr): ν = 3360, 3064, 3022, 1972, 1796, 1694, 1613, 1571, 1512, 1485, 1440, 1314, 1257, 1141, 1030, 1003, 982, 934, 746 cm$^{-1}$; HRMS (ESI+) m/z calcld for C_{17}H_{15}NNaO_{5}S$^+$ [M+Na]$^+$ = 320.0716, found = 320.0721.
General procedure for formal cycloaddition reaction

To a solution of corresponding allenic compound 2 (0.12 mmol, 1.2 eq.) in MeOH (0.5 ml) was quinidine (6.5 mg, 0.02 mmol, 0.2 eq.) added in one portion. The mixture was stirred for 10 minutes at room temperature. Then corresponding alkylidene compound 1 (0.1 mmol, 1.0 eq.) and 2,4-DNBA (2.1 mg, 0.01 mmol, 0.1 eq.) were added to the reaction mixture. The reaction was stirred for the indicated time.

**Method A:**
After the reaction was completed the solvent was evaporated. Crude product was purified by column chromatography (Hex/EtOAc mixtures).

**Method B:**
After the reaction was completed the precipitate was filtered and washed with minimal amount of cold MeOH.

**Benzyl (R,E)-2-(4-phenyl-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (3a)**

The title compound was synthesized according to general procedure (reaction time: 15 hours), affording the title compound as a white solid, 3a/4a ≥ 20:1.

**Method A:** Crude product was purified by column chromatography (hexane/EtOAc = 50:1), ee = 90 %; yield 3a = 92 %; \([\alpha]_D^{20} = -15.4 (c = 0.6, \text{CHCl}_3)\).

**Method B:** ee = 99 %; yield 3a = 73 %; \([\alpha]_D^{20} = -17.7 (c = 0.5, \text{CHCl}_3)\).

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 90:10, \( \lambda = 207 \text{ nm, } V = 1.0 \text{ ml/min, } t = 25 \text{ °C} \))

\( t_R = 5.8 \text{ min (major enan.)}, \ t_R = 10.0 \text{ min (minor enan.)}, \text{ m.p.} = 113.6 \text{ °C}, \ ^1\text{H NMR} \ (400 \text{ MHz, Chloroform-}d) \): \( \delta = 7.80 – 7.64 \text{ (m, 1H), 7.44 – 7.12 \text{ (m, 13H), 5.84 (d, } J = 1.5 \text{ Hz, 1H), 5.11 (q, } J = 12.5 \text{ Hz, 2H), 4.38 (dd, } J = 6.5, 4.3 \text{ Hz, 1H), 4.10 (dd, } J = 15.5, 4.3 \text{ Hz, 1H), 3.36 (ddd, } J = 15.4, 6.6, 1.6 \text{ Hz, 1H) ppm}; \ ^{13}\text{C NMR} \ (101 \text{ MHz, Chloroform-}d) \): \( \delta = 166.3, 165.9, 153.5, 141.4, 136.2, 136.0, 131.6, 128.7 (2C), 128.5 (2C), 128.1, 128.0 (2C), 127.4 (2C), 127.1, 124.8, 123.4, 122.4, 120.8, 112.3, 101.7, 65.8, 36.0, 31.1 \text{ ppm}; \text{IR (KBr)}: v = 3067, 3034, 2959, 2887, 2836, 1945, 1900, 1870, 1820, 1787, 1703, 1655, 1598, 1586, 1548, 1497, 1470, 1452, 1434, 1389, 1356, 1306, 1266, 1248, 1228, 1207, 1195, 1174, 1102, 1016, 1063, 1018, 988 \text{ cm}^{-1}; \text{HRMS (ESI+)} m/z: \text{calcd. for } C_{26}H_{20}NaO_3S^+ [M+Na]^+: 435.1025, \text{found: 435.1024}}


The title compound was synthesized according to general procedure (reaction time: 15 hours), affording the title compound as a white solid, 3b/4b ≥ 20:1.

**Method A:** Crude product was purified by column chromatography (hexane/EtOAc = 25:1), ee = 86 %; yield 3b = 82 %; \([\alpha]_D^{20} = 28.6 (c = 0.9, \text{CHCl}_3)\).

**Method B:** ee = 89 %, yield 3b = 80 %, \([\alpha]_D^{20} = 29.3 (c = 1.1, \text{CHCl}_3)\).
Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IA column (mobile phase: n-heptane/propan-2-ol – 97:3, λ = 232 nm, V = 1.0 ml/min, t = 25 °C) τR = 10.0 min (minor. enan.), τR = 10.7 min (major. enan.); m.p. = 104.3 °C; 1H NMR (400 MHz, Chloroform-δ) δ = 7.59 (d, J = 8.5 Hz, 1H), 7.39 – 7.21 (m, 8H), 7.21 – 7.07 (m, 4H), 5.83 (d, J = 1.5 Hz, 1H), 5.09 (q, J = 12.5 Hz, 2H), 4.33 (dd, J = 6.5, 4.0 Hz, 1H), 4.10 (dd, J = 15.4, 4.1 Hz, 1H), 3.30 (ddd, J = 15.4, 6.5, 1.6 Hz, 1H) ppm; 13C NMR (101 MHz, Chloroform-δ) δ = 166.1, 165.4, 156.0, 145.8, 140.4, 137.7, 136.5, 135.8, 129.0 (2C), 128.5 (2C), 128.5 (2C), 128.0, 127.3 (2C), 127.3, 123.8, 123.5, 120.5, 112.0, 102.2, 65.9, 35.9, 31.0 ppm; IR (KBr): ν = 3082, 3064, 3025, 3004, 2989, 2941, 2869, 2851, 2851, 1957, 1870, 1817, 1709, 1649, 1595, 1577, 1545, 1500, 1449, 1428, 1380, 1353, 1329, 1308, 1293, 1260, 1222, 1204, 1168, 1102, 1078, 1027, 994, 967, 863 cm⁻¹; HRMS (ESI+) m/z: calcd. for C₂₀H₁₉ClNaO₃S [M+Na]+: 469.0628, found: 469.0636.

The title compound was synthesized according to general procedure (reaction time: 15 hours), affording the title compound as a white solid, 3c/4c ≥ 20:1.

**Method A:** Crude product was purified by column chromatography (hexane/EtOAc = 7:1), ee = 80 %; yield 3c = 72 %; [α]D³⁰ = 52.2 (c = 1.4, CHCl₃).

**Method B:** ee = 80 %; yield 3c = 65 %; [α]D³⁰ = 48.1 (c = 0.5, CHCl₃).

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 90:10, λ = 280 nm, V = 1.0 ml/min, t = 25 °C) τR = 10.2 min (major enan.), τR = 10.9 min (minor enan.); m.p. = 98.8 °C; 1H NMR (400 MHz, Chloroform-δ): δ = 8.06 (dd, J = 8.8, 2.2 Hz, 1H), 7.98 (d, J = 2.2 Hz, 1H), 7.79 (d, J = 8.8 Hz, 1H), 7.40 – 7.26 (m, 8H), 7.21 – 7.14 (m, 2H), 5.87 (d, J = 1.4 Hz, 1H), 5.10 (q, J = 12.4 Hz, 2H), 4.43 (dd, J = 6.5, 4.4 Hz, 1H), 4.08 (dd, J = 15.4, 4.4 Hz, 1H), 3.39 (ddd, J = 15.4, 6.5, 1.6 Hz, 1H) ppm; 13C NMR (101 MHz, Chloroform-δ): δ = 165.9, 164.9, 156.0, 145.8, 140.4, 137.7, 136.5, 135.8, 129.0 (2C), 128.5 (2C), 128.2, 128.0 (2C), 127.6, 127.3 (2C), 123.0, 117.9, 116.1, 113.1, 102.8, 66.0, 36.1, 30.9 ppm; IR (KBr): ν = 3091, 3061, 3034, 2956, 2929, 2854, 1709, 1658, 1613, 1580, 1518, 1494, 1449, 1383, 1338, 1251, 1216, 1198, 1165, 1099, 1084, 1057, 1027, 991 cm⁻¹; HRMS (ESI+) m/z: calcd. for C₂₀H₁₉NNaO₃S [M+Na]+: 480.0871, found: 480.0876.

**Method A:** Crude product was purified by column chromatography (hexane/EtOAc = 15:1), ee = 89 %; yield 3e = 87 %; [α]D³⁰ = 43.7 (c = 1.0, CHCl₃).

**Method B:** ee = 90 %; yield 3e = 88 %; [α]D³⁰ = 45.4 (c = 0.8, CHCl₃).

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IA column (mobile phase: n-heptane/propan-2-ol – 97:3, λ = 234 nm, V = 1.0 ml/min, t = 25 °C) τR = 10.5 min (minor enan.), τR = 11.4 min (major enan.); m.p. = 116.9 °C; 1H NMR (400 MHz, Chloroform-δ): δ = 7.53 (d, J = 8.5 Hz, 1H), 7.39 – 7.22 (m, 10H), 7.18 – 7.13 (m, 2H), 5.82 (d, J = 1.5 Hz, 1H), 5.09 (q, J = 12.5 Hz, 2H), 4.33 (dd, J = 6.5, 3.9 Hz, 1H), 4.12 (dd, J = 15.4, 4.0 Hz, 1H), 3.28 (ddd, J = 15.4, 6.5, 1.6 Hz, 1H) ppm; 13C NMR (101 MHz, Chloroform-δ):
δ = 166.1, 165.5, 154.8, 140.8, 137.8, 136.0, 130.1, 128.8 (2C), 128.5 (2C), 128.1, 128.0 (2C), 127.3 (3C), 126.5, 123.8, 123.5, 118.9, 111.9, 102.2, 65.9, 35.9, 31.0 ppm; IR (KBr): ν = 3088, 3064, 3031, 2932, 2881, 2851, 1876, 1715, 1697, 1649, 1595, 1577, 1500, 1440, 1416, 1380, 1362, 1332, 1308, 1257, 1222, 1198, 1162, 1111, 1066, 1021 cm⁻¹; HRMS (ESI+) m/z: calcd. for C_{26}H_{19}BrNaO_{3}S [M+Na]^+: 513.0127, found: 513.0130.


The title compound was synthesized according to general procedure (reaction time: 15 hours), affording the title compound as a white solid; 3f/4f ≥ 20:1.

**Method A:** Crude product was purified by column chromatography (hexane/EtOAc = 25:1); ee = 83%; yield 3f = 86%; [α]_{D}^{20} = -8.9 (c = 0.8, CHCl₃).

**Method B:** ee = 87%; yield 3f = 82%; [α]_{D}^{20} = -10.0 (c = 1.1, CHCl₃).

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IA column (mobile phase: n-heptane/propan-2-ol – 97:3, λ = 206 nm, V = 1.0 mL/min, t = 25 °C) t_R = 10.1 min (minor enan.), t_R = 11.0 min (major enan.); m.p. = 136.1 °C; ^1H NMR (400 MHz, Chloroform-d): δ = 7.83 (d, J = 1.8 Hz, 1H), 7.41 – 7.29 (m, 7H), 7.28 – 7.23 (m, 1H), 7.23 – 7.09 (m, 2H), 6.97 (d, J = 8.5 Hz, 1H), 5.84 (d, J = 1.3 Hz, 1H), 5.12 (q, J = 12.5 Hz, 2H), 4.34 (dd, J = 6.5, 4.7 Hz, 1H), 4.01 (dd, J = 15.5, 4.7 Hz, 1H), 3.43 (ddd, J = 15.5, 6.5, 1.5 Hz, 1H) ppm; ^13C NMR (101 MHz, Chloroform-d): δ = 166.2, 165.5, 153.9, 141.1, 136.0, 135.1, 133.0, 128.8 (2C), 128.6 (2C), 128.2 (2C), 128.1 (2C), 127.4 (2C), 127.3, 124.9, 122.1, 116.6, 112.1, 102.1, 65.9, 36.2, 31.2 ppm; IR (KBr): ν = 3082, 3067, 3028, 3010, 2941, 2929, 2893, 2884, 2851, 1703, 1655, 1598, 1577, 1539, 1491, 1458, 1422, 1380, 1362, 1299, 1263, 1245, 1213, 1192, 1168, 1135, 1099, 1054, 1030, 991 cm⁻¹; HRMS (ESI+) m/z: calcd. for C_{26}H_{19}BrNaO_{3}S [M+Na]^+: 513.0121, found: 513.0131.

**Benzyl (R,E)-2-(8-bromo-4-phenyl-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (3g)**

The title compound was synthesized according to general procedure (reaction time: 15 hours), affording the title compound as a white solid, 3g/4g ≥ 20:1.

**Method A:** Crude product was purified by column chromatography (hexane/EtOAc = 25:1), ee = 87%; yield 3g = 78%; [α]_{D}^{20} = -43.5 (c = 0.9, CHCl₃).

**Method B:** ee = 90%; yield 3g = 83%; [α]_{D}^{20} = -45.0 (c = 1.2, CHCl₃).

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IA column (mobile phase: n-heptane/propan-2-ol – 97:3, λ = 206 nm, V = 1.0 mL/min, t = 25 °C) t_R = 8.0 min (minor enan.), t_R = 8.8 min (major enan.); m.p. = 123.8 °C; ^1H NMR (400 MHz, Chloroform-d): δ = 7.40 – 7.33 (m, 5H), 7.33 – 7.29 (m, 3H), 7.28 – 7.22 (m, 1H), 7.21 – 7.15 (m, 2H), 7.13 – 7.08 (m, 2H), 5.87 (d, J = 1.4 Hz, 1H), 5.12 (q, J = 12.5 Hz, 2H), 4.36 (dd, J = 6.5, 4.5 Hz, 1H), 4.06 (dd, J = 15.5, 4.5 Hz, 1H), 3.40 (ddd, J = 15.4, 6.5, 1.5 Hz, 1H) ppm; ^13C NMR (101 MHz, Chloroform-d): δ = 166.2, 165.4, 154.3, 141.1, 137.4, 136.0, 133.6, 128.8 (2C), 128.5 (2C), 128.1, 128.0 (2C), 127.4 (2C), 127.3, 126.2 (2C), 119.7, 115.8, 113.4, 102.2, 65.9, 36.4, 31.1 ppm; IR (KBr): ν = 3028, 2956, 1694, 1646, 1604, 1580, 1539, 1497, 1458, 1410, 1383, 1356, 1311, 1257, 1228, 1195, 1171, 1141, 1114, 1045, 1024, 961 cm⁻¹; HRMS (ESI+) m/z: calcd. for C_{26}H_{19}BrNaO_{3}S [M+Na]^+: 513.0121, found: 513.0131.

S20
Benzyl (R,E)-2-(4-(4-chlorophenyl)-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (3h)

The title compound was synthesized according to general procedure (reaction time: 15 hours), affording the title compound as a white solid, 3h/4h > 20:1.

**Method A:** Crude product was purified by column chromatography (hexane/EtOAc = 50:1), ee = 88 %; yield 3h = 82 %; [α]_D^20 = -12.5 (c = 0.8, CHCl_3).

**Method B:** ee = 93 %; yield 3h = 63 %; [α]_D^20 = -14.7 (c = 0.9, CHCl_3).

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 90:10, λ = 254 nm, V = 1.0 ml/min, t = 25 °C) t_R = 6.5 min (minor enan.), t_R = 14.0 min (major enan.). m.p. = 122.0 °C; _1^H NMR (400 MHz, Chloroform-δ): δ = 7.70 (dd, J = 5.9, 3.1 Hz, 1H), 7.39 – 7.29 (m, 5H), 7.25 – 7.21 (m, 4H), 7.17 – 7.14 (m, 1H), 7.10 (d, J = 8.4 Hz, 2H), 5.83 (s, 1H), 5.12 – 5.07 (m, 2H), 4.35 (dd, J = 6.3, 3.8 Hz, 1H), 4.13 (dd, J = 15.4, 3.8 Hz, 1H), 3.27 (dd, J = 15.9, 7.1 Hz, 1H) ppm; _13^C NMR (101 MHz, Chloroform-δ): δ = 166.2, 165.4, 153.8, 139.9, 136.0, 132.9, 131.7, 128.9 (2C), 128.8 (2C), 128.6 (2C), 128.2, 128.1 (2C), 124.9, 123.7, 122.6, 120.6, 111.7, 102.1, 65.9, 35.4, 30.9 ppm; IR (KBr): ν = 1700, 1646, 1595, 1580, 1551, 1491, 1461, 1431, 1383, 1350, 1311, 1269, 1204, 1156, 1108, 1021, 955, 920, 860, 758, 740 cm\(^{-1}\); HRMS (ESI+) m/z: calcd. for C_{29}H_{19}NaO_3ClS- [M+Na]^+; 469.0636, found: 469.0631.


The title compound was synthesized according to general procedure (reaction time: 15 hours), affording the title compound as a yellowish solid, 3i/4i > 20:1.

**Method A:** Crude product was purified by column chromatography (hexane/EtOAc = 50:1), ee = 80 %; yield 3x = 90 %; [α]_D^20 = -15.1 (c = 0.3, CHCl_3).

**Method B:** ee = 78 %; yield 3x = 37 %; [α]_D^20 = -10.0 (c = 0.5, CHCl_3).

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 80:20, λ = 254 nm, V = 1.0 ml/min, t = 25 °C) t_R = 10.3 min (minor enan.), t_R = 25.4 min (major enan.). m.p. = 118.3 °C; _1^H NMR (400 MHz, Chloroform-δ): δ = 7.81 – 7.69 (m, 1H), 7.61 – 7.49 (m, 2H), 7.38 (qd, J = 4.2, 2.0 Hz, 3H), 7.34 – 7.29 (m, 4H), 7.28 – 7.22 (m, 2H), 7.21 – 7.07 (m, 1H), 5.86 (d, J = 1.6 Hz, 1H), 5.20 – 5.02 (m, 2H), 4.45 (dd, J = 6.6, 3.5 Hz, 1H), 4.23 (dd, J = 15.4, 3.6 Hz, 1H), 3.28 (dd, J = 15.3, 6.6, 1.7 Hz, 1H) ppm; _13^C NMR (101 MHz, Chloroform-δ): δ = 166.1, 164.7, 154.3, 146.8, 135.9, 135.7, 132.6 (2C), 131.7, 128.6 (2C), 128.3 (3C), 128.1 (2C), 125.1, 123.9, 122.7, 120.3, 118.7, 111.2, 110.8, 102.6, 66.0, 36.0, 30.4 ppm; IR (KBr): ν = 2223, 1709, 1652, 1607, 1583, 1500, 1467, 1434, 1380, 1353, 1302, 1269, 1210, 1159, 1090, 1078, 1018, 985, 851, 764, 734, 698 cm\(^{-1}\); HRMS (ESI+) m/z: calcd. for C_{37}H_{20}O_3NS- [M+H]^+; 438.1158, found: 438.1154.

The title compound was synthesized according to general procedure (reaction time: 15 hours), affording the title compound as a transparent oil. 3j/4j = 15:1.

**Method A:** Crude product was purified by column chromatography (hexane/EtOAc = 50:1), ee = 84%; yield 3j = 80%; [α]D²⁰ = -4.4 (c = 1.2, CHCl₃).

**Method B:** ee = 75%; yield 3j = 53%; [α]D²⁰ = -2.1 (c = 1.0, CHCl₃).

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 90:10, λ = 254 nm, V = 1.0 ml/min, t = 25 °C) tₐ = 7.0 min (minor enan.), t₁ = 17.8 min (major enan.); ¹H NMR (400 MHz, Chloroform-d): δ = 7.80 – 7.68 (m, 1H), 7.60 – 7.49 (m, 2H), 7.41 – 7.27 (m, 7H), 7.24 (q, J = 4.0, 3.5 Hz, 2H), 7.20 – 7.07 (m, 1H). 5.85 (d, J = 1.5 Hz, 1H), 5.21 – 5.00 (m, 2H). 4.44 (dd, J = 6.6, 3.7 Hz, 1H). 4.21 (dd, J = 15.4, 3.7 Hz, 1H). 3.29 (ddd, dd, J = 15.4, 6.7, 1.7 Hz, 1H ppm; ¹³C NMR (101 MHz, Chloroform-d): δ = 166.2, 165.1, 154.1, 145.5, 135.9 (2C), 131.7, 129.4 (q, J = 32.5 Hz, 1H), 128.6 (2C), 128.2, 128.1 (2C), 127.8 (2C), 125.8 (q, J = 3.8 Hz, 2C), 125.0, 123.8 (q, J = 272.2 Hz) 123.8, 122.6, 120.5, 111.3, 102.3, 66.0, 35.8, 30.7 ppm; ¹⁹F NMR (376 MHz, Chloroform-d): δ = -62.40 ppm; IR (KBr): ν = 3067, 3034, 2956, 1712, 1655, 1601, 1583, 1524, 1494, 1467, 1440, 1416, 1383, 1356, 1323, 1269, 1198, 1162, 1105, 1069, 1015, 988, 845, 761, 731, 701, 609 cm⁻¹; HRMS (ESI+) m/z: calcd. for C₂₇H₂₀O₃F₃S⁺ [M+H⁺]: 481.1080, found: 481.1076.


The title compound was synthesized according to general procedure (reaction time: 15 hours), affording the title compound as a yellow solid, 3k/4k = 17:1.

**Method A:** Crude product was purified by column chromatography (hexane/EtOAc = 20:1), ee = 75%; yield 3k = 72%; [α]D²⁰ = -12.8 (c = 0.6, CHCl₃).

**Method B:** ee = 73%; yield 3k = 73%; [α]D²⁰ = -13.6 (c = 0.3, CHCl₃).

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 80:20, λ = 254 nm, V = 1.0 ml/min, t = 25 °C) tₐ = 9.8 min (minor enan.), t₁ = 24.2 min (major enan.). m.p. = 114 °C; ¹H NMR (400 MHz, Chloroform-d): δ = 8.11 (d, J = 8.8 Hz, 2H), 7.73 – 7.70 (m, 1H), 7.34 – 7.32 (m, 5H), 7.28 – 7.24 (m, 4H), 7.14 – 7.12 (m, 1H). 5.84 (d, J = 1.5 Hz, 1H). 5.14 – 5.03 (m, 2H). 4.49 (dd, J = 6.7, 3.5 Hz, 1H). 4.24 (dd, J = 15.3, 3.5 Hz, 1H). 3.27 (ddd, J = 15.4, 6.7, 1.7 Hz, 1H) ppm; ¹³C NMR (101 MHz, Chloroform-d): δ = 166.1, 164.5, 154.4, 148.8, 147.1, 135.8, 135.7, 131.6, 128.5 (2C), 128.3 (2C), 128.3, 128.1 (2C), 125.1, 124.0 (2C), 123.9, 122.7, 120.2, 110.7, 102.7, 66.0, 35.7, 30.4 ppm; IR (KBr): ν = 1712, 1655, 1601, 1583, 1524, 1467, 1437, 1386, 1350, 1299, 1269, 1204, 1159, 1102, 1021, 988, 964, 857, 752, 731, 701 cm⁻¹; HRMS (ESI+) m/z: calcd. for C₂₆H₁₉NO₅S⁺ [M+Na⁺]: 480.0876, found: 480.0871.

The title compound was synthesized according to general procedure (reaction time: 15 hours), affording the title compound as a white solid, 3I/4I > 20:1.

Method A: Crude product was purified by column chromatography (hexane/EtOAc = 50:1), ee = 85 %; yield 3I = 90 %; \([\alpha]^2_\text{D} = -20.9 \ (c = 0.4, \text{CHCl}_3)\).

Method B: ee = 85%; yield 3I = 62 %; \([\alpha]^2_\text{D} = -17.3 \ (c = 0.7, \text{CHCl}_3)\).

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 90:10, \(\lambda = 254 \text{ nm}, V = 1.0 \text{ ml/min}, t = 25 \text{ °C}\) \(t_R = 7.1 \text{ min (minor enan.)}, t_R = 10.8 \text{ min (major enan.)}, \text{ m.p.} = 143 \text{ °C}; \text{ H NMR (400 MHz, Chloroform-d)}: \delta = 7.70 – 7.66 (m, 1H), 7.37 – 7.28 (m, 5H), 7.23 – 7.18 (m, 2H), 7.17 – 7.14 (m, 1H), 7.08 (d, \(J = 8.6 \text{ Hz}, 2H\)), 6.79 (d, \(J = 8.7 \text{ Hz}, 2H\)), 5.80 (d, \(J = 1.4 \text{ Hz}, 1H\)), 5.10 (q, \(J = 12.5 \text{ Hz, 2H}\)), 4.32 (dd, \(J = 6.5, 4.1 \text{ Hz, 1H}\)), 4.06 (dd, \(J = 15.4, 4.2 \text{ Hz, 1H}\)), 3.76 (s, 3H), 3.30 (ddd, \(J = 15.4, 6.5, 1.6 \text{ Hz, 1H}\) ppm; \text{ 13C NMR (101 MHz, Chloroform-d)}: \(\delta = 166.3, 166.1, 158.6, 153.4, 136.3, 136.1, 131.6, 128.5 (2C), 128.4 (2C), 128.1, 128.0 (2C), 124.8, 123.4, 122.4, 120.9, 114.0 (2C), 112.6, 101.7, 65.8, 55.2, 35.3, 31.3 ppm; IR (KBr): \(\nu = 3061, 3040, 2998, 2950, 2929, 2899, 2642, 1709, 1655, 1613, 1583, 1548, 1509, 1461, 1440, 1386, 1356, 1302, 1254, 1216, 1156, 1105, 1078, 1036, 1027, 985, 848, 836, 758, 737, 695 \text{ cm}^{-1}; \text{ HRMS (ESI+)} /m/z/: \text{ calcd. for C}_{27}\text{H}_{22}\text{NaO}_{3}\text{S}^+ [\text{M+Na}^+]: 465.1131, \text{ found}: 465.1129).
Benzyl (R,E)-2-(4-(4-bromophenyl)-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (3n)

The title compound was synthesized according to general procedure (reaction time: 15 hours), affording the title compound as a yellowish solid, 3n/4n > 20:1.

**Method A**: Crude product was purified by column chromatography (hexane/EtOAc = 50:1), ee = 86 %; yield 3n = 86 %; [α]D20 = -9.5 (c = 0.6, CHCl3).

**Method B**: ee = 90 %; yield 3n = 53 %; [α]D20 = -12.0 (c = 0.8, CHCl3).

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 90:10, λ = 254 nm, V = 1.0 ml/min, t = 25 °C) tR = 7.2 min (minor enan.), tR = 15.2 min (major enan.). m.p. = 126.8 °C; 1H NMR (400 MHz, Chloroform-d): δ = 7.71 – 7.67 (m, 1H), 7.39 – 7.28 (m, 7H), 7.24 – 7.22 (m, 2H), 7.15 – 7.13 (m, 1H), 7.04 (d, J = 8.4 Hz, 2H), 5.82 (d, J = 1.6 Hz, 1H), 5.14 – 5.06 (m, 2H), 4.33 (dd, J = 6.5, 3.8 Hz, 1H), 4.12 (dd, J = 15.4, 3.8 Hz, 1H), 3.26 (dd, J = 15.4, 6.6, 1.7 Hz, 1H) ppm; 13C NMR (101 MHz, Chloroform-d): δ = 166.2, 165.3, 153.8, 140.4, 136.0 (2C), 131.8 (2C), 131.6, 129.1 (2C), 128.6 (2C), 128.2, 128.0 (2C), 124.9, 123.6, 122.5, 121.0, 120.6, 111.6, 102.1, 65.9, 35.5, 30.8 ppm; IR (KBr): ν = 3064, 3031, 2926, 2893, 2857, 1948, 1903, 1867, 1826, 1784, 1691, 1646, 1604, 1580, 1491, 1461, 1431, 1377, 1347, 1317, 1269, 1237, 1204, 1162, 1111, 1078, 1024, 1009, 952, 920, 869, 851, 812, 764, 740, 692 cm⁻¹; HRMS (ESI+) m/z: calcd. for C26H20BrO3S⁺ [M+H]⁺: 491.0311, found: 491.0306.


The title compound was synthesized according to general procedure (reaction time: 15 hours), affording the title compound as a yellow solid, 3o/4o > 20:1.

**Method A**: Crude product was purified by column chromatography (hexane/EtOAc = 50:1), ee = 85 %; yield 3o = 94 %; [α]D20 = -26.3 (c = 0.5, CHCl3).

**Method B**: ee = 86 %; yield 3o = 63 %; [α]D20 = -23.5 (c = 1.5, CHCl3).

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 80:20, λ = 254 nm, V = 1.0 ml/min, t = 25 °C) tR = 6.2 min (minor enan.), tR = 12.4 min (major enan.). m.p. = 132 °C; 1H NMR (400 MHz, Chloroform-d): δ = 7.71 – 7.69 (m, 1H), 7.39 – 7.30 (m, 7H), 7.25 – 7.22 (m, 2H), 7.16 – 7.09 (m, 3H), 5.85 (d, J = 1.5 Hz, 1H), 5.16 – 5.08 (m, 2H), 4.33 (dd, J = 6.6, 4.0 Hz, 1H), 4.08 (dd, J = 15.5, 4.0 Hz, 1H), 3.31 (ddd, J = 15.5, 6.6, 1.6 Hz, 1H) ppm; 13C NMR (101 MHz, Chloroform-d): δ = 166.16, 165.14, 153.90, 143.81, 135.95, 135.89, 131.59, 130.42, 130.35, 130.29, 128.52 (2C), 128.11, 128.01 (2C), 126.06, 124.90, 123.62, 122.75, 122.50, 120.62, 111.37, 102.14, 65.91, 35.70, 30.89 ppm; IR (KBr): ν = 3061, 3034, 2950, 2932, 1712, 1658, 1586, 1464, 1434, 1386, 1356, 1299, 1266, 1216, 1156, 1102, 1072, 1021, 997, 929, 851, 788, 755, 734, 692 cm⁻¹; HRMS (ESI+) m/z: calcd. for C26H20BrO3S⁺ [M+H]⁺: 491.0311, found: 491.0303.


S24
The title compound was synthesized according to general procedure (reaction time: 15 hours), affording the title compound as a white wax. \(3p/4p = 6:1\).

Method A: Crude product was purified by column chromatography (hexane/EtOAc = 50:1); \(ee = 89\%\); yield \(3p = 58\%\); \([\alpha]_D^{10} = -11.0\) (c = 0.3, CHCl3).

Method B: \(ee = 88\%\); yield \(3p = 42\%\); \([\alpha]_D^{10} = -13.5\) (c = 1.1, CHCl3).

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IA column (mobile phase: n-heptane/propan-2-ol – 97:3, \(\lambda = 254\) nm, \(V = 1.0\) ml/min, \(t = 25\) °C); \(t_R = 6.1\) min (major enan.), \(t_R = 7.7\) min (minor enan.); \(^1\)H NMR (400 MHz, Chloroform-d): \(\delta = 7.71 – 7.67\) (m, 1H), 7.63 – 7.61 (m, 1H), 7.36 – 7.31 (m, 3H), 7.28 – 7.26 (m, 2H), 7.23 – 7.21 (m, 2H), 7.16 – 7.14 (m, 1H), 7.11 – 7.06 (m, 2H), 6.85 – 6.82 (m, 1H), 5.83 (d, \(J = 1.6\) Hz, 1H), 5.13 – 5.02 (m, 2H), 4.89 (dd, \(J = 6.9, 3.3\) Hz, 1H), 4.18 (dd, \(J = 15.5, 3.2\) Hz, 1H), 3.21 (ddd, \(J = 15.5, 6.9, 1.7\) Hz, 1H) ppm; \(^{13}\)C NMR (101 MHz, Chloroform-d): \(\delta = 166.0, 165.0, 154.3, 140.0, 136.0, 135.8, 133.2, 131.6, 128.9, 128.7, 128.5 (2C), 128.1, 128.0 (2C), 127.7, 124.9, 123.7, 123.7, 122.4, 120.7, 111.4, 102.6, 65.9, 35.2, 29.4 ppm; IR (KBr): \(\nu = 3072, 3032, 2962, 2937, 2890, 1692, 1649, 1574, 1494, 1462, 1437, 1383, 1352, 1312, 1278, 1208, 1154, 1112, 1075, 1029, 1002, 957, 926, 856, 761, 743, 695\) cm\(^{-1}\); HRMS (ESI+) m/z: calcld. for C\(_{26}\)H\(_{30}\)BrO\(_3\)S\(_3\)+ [M+H]\(^+\): 491.0311, found: 491.0304.

Benzyll \((R,E)-2-(4-(furan-3-yl)-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (3q)

The title compound was synthesized according to general procedure (reaction time: 15 hours), affording the title compound as a yellow oil. \(3q/4q > 20:1\) (Slow decomposition of product was observed by staying longer time into CDCl\(_3\) – see carbon spectra).

Method A: Crude product was purified by column chromatography (hexane/EtOAc = 50:1); \(ee = 66\%\); yield \(3q = 82\%\); \([\alpha]_D^{10} = 19.6\) (c = 1.1, CHCl3).

Method B: \(ee = 66\%\); yield \(3q = 46\%\); \([\alpha]_D^{10} = 15.3\) (c = 0.7, CHCl3).

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 90:10, \(\lambda = 254\) nm, \(V = 1.0\) ml/min, \(t = 25\) °C); \(t_R = 6.69\) min (minor enan.), \(t_R = 10.6\) min (major enan.); \(^1\)H NMR (400 MHz, Chloroform-d): \(\delta = 7.79\) (d, \(J = 7.9\) Hz, 1H), 7.51 – 7.43 (m, 1H), 7.43 – 7.21 (m, 8H), 6.24 (dd, \(J = 3.2, 1.9\) Hz, 1H), 6.03 (d, \(J = 3.2\) Hz, 1H), 5.86 (d, \(J = 1.6\) Hz, 1H), 5.28 – 5.10 (m, 2H), 4.47 (dt, \(J = 11.7, 3.4\) Hz, 2H), 3.10 (ddd, \(J = 16.1, 7.0, 1.7\) Hz, 1H) ppm; \(^{13}\)C NMR (101 MHz, Chloroform-d): \(\delta = 166.5, 165.8, 153.9, 153.5, 142.1, 136.2, 136.1, 131.5, 128.6 (2C), 128.2, 128.1 (2C), 125.0, 123.6, 122.4, 120.63, 110.5, 110.2, 106.3, 101.9, 66.0, 29.6, 27.5 ppm; IR (KBr): \(\nu = 3061, 3031, 2959, 2929, 1712, 1661, 1601, 1586, 1553, 1503, 1467, 1437, 1383, 1350, 1308, 1269, 1210, 1171, 1156, 1144, 1105, 1021, 994, 958, 931, 917, 887, 854, 812, 761, 737, 701\) cm\(^{-1}\); HRMS (ESI+) m/z: calcld. for C\(_{26}\)H\(_{31}\)NaO\(_3\)S\(_3\)+ [M+Na]\(^+\): 425.0818, found: 425.0813.


The title compound was synthesized according to general procedure (reaction time: 15 hours), affording the title compound as a yellowish oil. \(3r/4r = 20:1\).

Method A: Crude product was purified by column chromatography (hexane/EtOAc = 100:1); \(ee = 89\%\); yield \(3r = 36\%\); \([\alpha]_D^{10} = -14.3\) (c = 0.5, CHCl3).

\[\text{111.4, 1156, 1171, 1201, 1210, 1269, 1350, 1308, 1269, 1210, 1171, 1156, 1144, 1105, 1021, 994, 958, 931, 917, 887, 854, 812, 761, 737, 701}\] cm\(^{-1}\); HRMS (ESI+) m/z: calcld. for C\(_{26}\)H\(_{31}\)NaO\(_3\)S\(_3\)+ [M+Na]\(^+\): 425.0818, found: 425.0813.
**Method B:** No precipitate was observed.

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 90:10, \( \lambda = 254 \text{ nm, } V = 1.0 \text{ ml/min, } t = 25 ^\circ \text{C} \))

\( \tau_R = 4.6 \text{ min (minor enan.), } \tau_R = 5.9 \text{ min (major enan.).} \)

\( ^1 \text{H NMR (300 MHz, Chloroform-d): } \delta = 7.68 (d, J = 7.9 \text{ Hz, 1H}), 7.51 (d, J = 7.7 \text{ Hz, 1H}), 7.40 – 7.33 (m, 6H), 7.24 – 7.21 (m, 1H), 5.85 (s, 1H), 5.26 – 5.15 (m, 2H), 4.32 (d, J = 15.5 \text{ Hz, 1H}), 3.20 – 3.13 (m, 1H), 2.59 (dd, J = 15.4, 6.1 \text{ Hz, 1H}), 1.62 – 1.40 (m, 4H), 0.91 (t, J = 6.7 \text{ Hz, 3H}) \text{ ppm;} ^13 \text{C NMR (101 MHz, Chloroform-d): } \delta = 167.3, 166.8, 152.0, 136.5, 136.2, 131.7, 128.6 (2C), 128.12, 128.13 (2C), 124.7, 123.2, 122.5, 120.1, 115.2, 101.4, 65.9, 36.8, 29.7, 27.2, 20.6, 14.1 ppm; IR (KBr): \nu = 3082, 3063, 3051, 2937, 2871, 1712, 1643, 1602, 1588, 1547, 1501, 1467, 1422, 1365, 1315, 1288, 1278, 1203, 1186, 1175, 1155, 1124, 1069, 1056, 1024, 1007 cm\(^{-1}\); HRMS (ESI+) \text{ m/z: calcd. for } \text{C}_{23}\text{H}_{25}\text{NaO}_{3}S^+ \text{ [M+H]^+ : 379.1362, found: 379.1361.}

**Benzyl (R,E)-2-(4-cyclohexyl-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (3s)**

The title compound was synthesized according to general procedure (reaction time: 20 hours), affording the title compound as a colorless oil. \( 3s/4s = 20:1. \)

**Method A:** Crude product was purified by column chromatography (hexane/toluene = 3:1), \( ee = 89 \% ; \) yield \( 3s = 61 \% ; \) \( [\alpha]_{D}^{20} = 81.6 \)

\( c = 0.8, \text{ CHCl}_3. \)

**Method B:** No precipitate was observed.

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IA column (mobile phase: n-heptane/propan-2-ol – 97:3, \( \lambda = 293 \text{ nm, } V = 1.0 \text{ ml/min, } t = 25 ^\circ \text{C} \))

\( \tau_R = 5.0 \text{ min (major enan.), } \tau_R = 5.9 \text{ min (minor enan.).} \)

\( ^1 \text{H NMR (400 MHz, Chloroform-d): } \delta = 7.70 (dt, J = 7.9, 0.9 \text{ Hz, 1H}), 7.55 (dt, J = 8.0, 1.0 \text{ Hz, 1H}), 7.46 – 7.33 (m, 6H), 7.27 – 7.23 (m, 1H), 5.81 (d, J = 2.0 \text{ Hz, 1H}), 5.33 – 5.16 (m, 2H), 4.51 (dd, J = 16.0, 1.8 \text{ Hz, 1H}), 2.97 (td, J = 6.7, 1.8 \text{ Hz, 1H}), 2.49 (ddd, J = 16.1, 6.3, 2.2 \text{ Hz, 1H}), 1.86 – 1.77 (m, 1H), 1.76 – 1.67 (m, 2H), 1.67 – 1.60 (m, 2H), 1.52 (ddd, J = 11.1, 7.4, 3.4 \text{ Hz, 1H}), 1.27 – 0.95 \text{ (m, 5H)} \text{ ppm;} ^13 \text{C NMR (101 MHz, Chloroform-d): } \delta = 168.4, 166.8, 152.2, 137.1, 136.3, 131.7, 128.5 (2C), 128.1 (3C), 124.6, 123.2, 122.4, 120.9, 114.5, 100.2, 65.8, 42.5, 35.7 (2C), 30.4, 26.4 (2C), 26.3, 25.4 ppm; IR (KBr): \nu = 3893, 3858, 3827, 3610, 3790, 3739, 3727, 3704, 3682, 3663, 3534, 3088, 3064, 3032, 2925, 2851, 2793, 2670, 2359, 23359, 2176, 1948, 1895, 1863, 1813, 1775, 1709, 1654, 1648, 1598, 1580, 1549, 1512, 1496, 1464, 1449, 1435, 1386, 1354, 1314, 1271, 1253, 1237, 1212, 1185, 1173, 1155, 1115, 1075, 1020, 1003, 995, 958, 930, 846, 820, 788, 755, 728, 695 \text{ cm}^{-1}; \) HRMS (ESI+) \text{ m/z: calcd. for } \text{C}_{27}\text{H}_{27}\text{NO}_{3}S^+ \text{ [M+H]^+ : 419.1678, found: 419.1676.}


The title compound was synthesized according to general procedure (reaction time: 40 hours), affording the title compound as a white solid; \( 3s/4s \geq 20:1. \)

**Method A:** Crude product was purified by column chromatography (hexane/EtOAc = 25:1), \( ee = 89 \% ; \) yield \( 3s = 83 \% ; \) \( [\alpha]_{D}^{20} = -26.0 \text{ (c = 1.0, CHCl}_3). \)

**Method B:** \( ee = 98 \% ; \) yield \( 3s = 62 \% ; \) \( [\alpha]_{D}^{20} = -45.5 \text{ (c = 0.5, CHCl}_3. \)

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 90:10, \( \lambda = 206 \text{ nm, } V = 1.0 \text{ ml/min, } t = 25 ^\circ \text{C} \))

\( \tau_R = 5.0 \text{ min (minor enan.), } \tau_R = 9.1 \text{ min (major enan.)}; \) \text{m.p.} = 131.6 ^\circ \text{C}; \) \text{HRMS (400 MHz,}
Chloroform-d: δ = 7.73 – 7.66 (m, 1H), 7.34 – 7.23 (m, 3H), 7.23 – 7.18 (m, 4H), 7.17 – 7.12 (m, 1H), 5.77 (d, J = 1.5 Hz, 1H), 4.37 (dd, J = 6.6, 4.3 Hz, 1H), 4.08 (dd, J = 15.5, 4.3 Hz, 1H), 3.65 (s, 3H), 3.35 (ddd, J = 15.5, 6.6, 1.6 Hz, 1H) ppm; 13C NMR (101 MHz, Chloroform-d): δ = 166.9, 165.6, 153.5, 141.4, 136.2, 131.6, 128.7 (2C), 127.4, 127.7 (2C), 124.8, 123.4, 122.4, 120.8, 112.3, 101.5, 51.2, 36.0, 31.0 ppm; IR (KBr): ν = 3070, 3061, 3016, 2956, 2950, 2884, 2833, 1709, 1640, 1601, 1574, 1548, 1500, 1464, 1434, 1356, 1317, 1287, 1269, 1201, 1180, 1156, 1114, 1069, 1024, 1009 cm⁻¹; HRMS (ESI+) m/z: calcd. for C26H16NaO3S [M+Na]+: 359.0709, found: 359.0712.


The title compound was synthesized according to general procedure (reaction time: 48 hours), affording the title compound as a yellowish wax. 6a/7a > 20:1 (Note: Slow decomposition of product was observed by staying longer time into CDCl₃ – see carbon spectra).

**Method A:** Crude product was purified by column chromatography (hexane/EtOAc = 70:1), ee = 98 %; yield 6a = 52 %; [α]D²⁰ = -108.5 (c = 0.5, CHCl₃).

**Method B:** ee = 98 %; yield 6a = 49 %; [α]D²⁰ = -103.8 (c = 0.3, CHCl₃).

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 90:10, λ = 254 nm, V = 1.0 ml/min, t = 25 °C)

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 90:10, λ = 254 nm, V = 1.0 ml/min, t = 25 °C)

**Benzyll (R,E)-2-(2,7-diphenyl-6,7-dihydro-5H-pyrrano[2,3-d]thiazol-5-ylidene)acetate (6b)**

The title compound was synthesized according to general procedure (reaction time: 24 hours), affording the title compound as a white solid; crystals suitable for X-ray analysis were grown from boiling n-heptane/i-PrOH mixture (9:1), 6b/7b ≥ 20:1.

**Method A:** Crude product was purified by column chromatography (hexane/EtOAc = 10:1), ee = 98 %; yield 6b = 66 %; [α]D²⁰ = -45.2 (c = 1.1, CHCl₃).

**Method B:** ee = 99 %; yield 6b = 68 %; [α]D²⁰ = -47.3 (c = 0.7, CHCl₃).

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 80:20, λ = 208 nm, V = 1.0 ml/min, t = 25 °C)

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 80:20, λ = 208 nm, V = 1.0 ml/min, t = 25 °C)
The title compound was synthesized according to general procedure (reaction time: 10 hours), affording the title compound as a white solid; 

$$\frac{6c}{7c} > 20:1. $$

Method A: Crude product was purified by column chromatography (hexane/EtOAc = 50:1), ee = 87%; yield 6c = 92%; $\left[\alpha\right]_D^{20} = 5.3$ (c = 0.8, CHCl$_3$).

Method B: ee = 98%; yield 6c = 42%; $\left[\alpha\right]_D^{20} = 7.7$ (c = 0.3, CHCl$_3$).

Enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: $n$-heptane/propan-2-ol – 80:20, $\lambda$ = 210 nm, $V$ = 1.0 ml/min, $t$ = 25 °C), $t_R = 5.9$ min (minor enan.), $t_{R} = 29.2$ min (major enan.); m.p. = 127 °C; $^1$H NMR (400 MHz, Chloroform-$d$): $\delta = 7.87 - 7.75$ (m, 2H), $7.43 - 7.27$ (m, 10H), $7.26 - 7.20$ (m, 3H), 5.82 (d, $J = 1.4$ Hz, 1H), 5.22 – 5.07 (m, 2H), 4.45 (dd, $J = 6.4, 4.2$ Hz, 1H), 4.18 (dd, $J = 15.6, 4.3$ Hz, 1H), 3.33 (ddd, $J = 15.7, 6.5, 1.6$ Hz, 1H) ppm; $^{13}$C NMR (101 MHz, Chloroform-$d$): $\delta = 166.2$, 165.5, 155.5, 149.4, 141.0, 136.0, 135.6, 133.6, 129.7, 128.9 (2C), 128.6 (2C), 128.5 (2C), 128.1 (3C), 127.4 (2C), 127.0, 125.8 (2C), 101.9, 65.9, 37.9, 30.5 ppm; IR (KBr): $\nu = 3028$, 3004, 2956, 2893, 2854, 1715, 1655, 1559, 1491, 1467, 1452, 1383, 1347, 1242, 1159, 1099, 1024, 994, 961, 943, 920, 857, 764, 746, 701 cm$^{-1}$; HRMS (ESI+) $m/z$: calcd. for C$_{27}$H$_{22}$O$_3$NS$^+$ [M+H]$^+$: 440.1315, found: 440.1307.
Further transformations

Benzyl (R)-2-(4-phenyl-4H-benzo[4,5]thieno[2,3-b]pyran-2-yl)acetate (4a)

To a stirred solution of 3a (41.3 mg, 0.10 mmol, 1.0 eq.) in DMSO (5 ml) DBU (18 µl, 0.12 mmol, 1.2 eq.) was added in one portion at room temperature. At same temperature reaction was stirred for 24 h. Mixture was diluted with brine (20 ml) and this solution was washed with EtOAc (4 × 10 ml). Organic phase was dried under anhydrous MgSO₄. Mixture was filtered and solvents were evaporated in vacuo. Crude product was purified by column chromatography (hex / EtOAc = 15:1), affording the title compound as yellow oil.

Yield 4a = 77 %; ee = 99 %; the enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 90:10, λ = 284 nm, V = 1.0 ml/min, t = 25 °C) tR = 7.1 min (minor enan.), tR = 9.7 min (major enan.), [α]D²⁰ = 142.6 (c = 0.9, CHCl₃); ¹H NMR (400 MHz, Chloroform-d): δ = 7.71 – 7.64 (m, 1H), 7.41 – 7.33 (m, 5H), 7.33 – 7.29 (m, 4H), 7.26 – 7.10 (m, 4H), 5.22 (d, J = 3.1 Hz, 2H), 5.17 – 5.10 (m, 1H), 4.87 (d, J = 3.8 Hz, 1H), 3.36 (s, 2H) ppm; ¹³C NMR (101 MHz, Chloroform-d): δ = 169.0, 143.9, 143.8, 136.4, 135.6, 131.8, 128.7 (2C), 128.6 (2C), 128.3, 128.1 (2C), 128.0 (2C), 126.9, 124.5, 123.3 (2C), 122.1, 121.3, 109.4, 106.0, 66.9, 39.2, 39.1 ppm; IR (KBr): ν = 3402, 3064, 3055, 3028, 3004, 2956, 2926, 2851, 1736, 1724, 1694, 1655, 1598, 1589, 1551, 1497, 1437, 1380, 1311, 1257, 1216, 1159, 1072, 1030 cm⁻¹; HRMS (ESI+) m/z: calcd. for C₂₆H₂₀NaO₃S [M+Na]⁺: 435.1021, found: 435.1025.

Benzyl (R.E)-2-(9,9-dioxido-4-phenyl-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (8)

To a stirred solution of 3a (82.6 mg, 0.20 mmol, 1.0 eq.) in DCM (4 ml) MCPBA (40 % w/w) (190 mg, 0.44 mmol, 2.2 eq.) was added in one portion at room temperature. At same temperature reaction was stirred for 24 h. Solution was washed with sat. solution of NaHCO₃ (2 × 2 ml) and brine (2 ml). Organic phase was dried under anhydrous MgSO₄. Mixture was filtered and solvents were evaporated in vacuo. Crude product was purified by column chromatography (Hex / EtOAc = 3:1), affording the title compound as yellow solid.

Yield 8 = 82 %; ee = 99 %; the enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: n-heptane/propan-2-ol – 60:40,
\( \lambda = 254 \text{ nm}, V = 1.0 \text{ ml/min}, t = 25^\circ \text{C} \) \( t_R = 8.1 \text{ min} \) (minor enan.), \( t_R = 14.3 \text{ min} \) (major enan.), \([\alpha]_D^{20} = -78.9 \) (c = 1.0, CHCl); \textbf{m.p.} = 174.5 \text{ °C}; \textbf{1H NMR} (400 MHz, Chloroform-\( d \)): \( \delta = 7.64 \) (dd, \( J = 5.6, 3.0 \) Hz, 1H), 7.37 – 7.28 (m, 10H), 7.23 – 7.21 (m, 2H), 6.85 (dd, \( J = 5.7, 3.0 \) Hz, 1H), 5.99 (d, \( J = 1.4 \) Hz, 1H), 5.09 (q, \( J = 12.4 \) Hz, 2H), 4.13 (dd, \( J = 6.7, 4.2 \) Hz, 1H), 3.94 (dd, \( J = 15.7, 4.3 \) Hz, 1H), 3.34 (dd, \( J = 15.7, 6.6 \), 1.6 Hz, 1H) ppm; \textbf{13C NMR} (101 MHz, Chloroform-\( d \)): \( \delta = 165.5, 162.9, 148.9, 138.6, 135.6, 133.8, 132.6, 129.4, 129.24 \) (2C), 128.6, 128.5 (2C), 128.2, 128.02, 127.99 (2C), 127.3 (2C), 121.8, 121.2, 114.7, 104.8, 66.2, 35.1, 30.6 ppm; \textbf{IR} (KBr): \( \nu = 3070, 3037, 2666, 2612, 2558, 1718, 1652, 1589, 1580, 1467, 1449, 1425, 1383, 1350, 1311, 1284, 1266, 1213, 1156, 1096, 1042, 1018, 982, 937, 851, 767, 752, 734, 707, 659 \text{ cm}^{-1} \); \textbf{HRMS} (ESI+) \( m/z \): calcd. for \( \text{C}_{26}\text{H}_{21}\text{NaO}_3\text{S}^+ [\text{M+H}]^+ \): 445.1104, found: 445.1104.

**Benzyl** 2-((2S,4R)-4-phenyl-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-yl)acetateacetate (9)

Solution of 3a (100 mg, 0.24 mmol, 1.0 eq.) in dry THF (5.0 ml) was degassed (flask was evacuated and refilled with Ar three times) and Pd/C (10%, 25.4 mg, 0.1 eq.) was added. The reaction flask was evacuated again and refilled with \( \text{H}_2 \) three times. The resulting suspension was stirred 4.5 hrs at 35 \text{ °C}. (Note: Longer reaction time caused debenzylation). The reaction mixture was filtered through short pad of Celite (washed with EtOAc), solvents were evaporated and the residue was purified by column chromatography (hex / EtOAc = 12:1).

Yield 9 = 52%; \textit{ee} = 99%; the enantiomeric excess of product was determined by HPLC using chiral HPLC with an IB column (mobile phase: \( n \)-heptane/propan-2-ol – 90:10, \( \lambda = 207 \text{ nm}, V = 1.0 \text{ ml/min}, t = 25^\circ \text{C} \) \( t_R = 9.2 \text{ min} \) (major enan.), \( t_R = 20.0 \text{ min} \) (minor enan.), \([\alpha]_D^{20} = 110.7 \) (c = 1.0, CHCl); \textbf{1H NMR} (400 MHz, Chloroform-\( d \)): \( \delta = 7.60 \) (dd, \( J = 7.9, 1.1 \) Hz, 1H), 7.44 – 7.32 (m, 3H), 7.32 – 7.15 (m, 7H), 7.09 (td, \( J = 7.6, 1.2 \) Hz, 1H), 6.99 (td, \( J = 7.8, 1.1 \) Hz, 1H), 6.62 (dd, \( J = 8.0, 1.2 \) Hz, 1H), 5.20 (s, 2H), 4.77 (dd, \( J = 11.3, 7.5, 6.0, 1.7 \) Hz, 1H), 4.23 (dd, \( J = 10.9, 6.5 \) Hz, 1H), 2.94 (dd, \( J = 15.9, 7.2 \) Hz, 1H), 2.72 (dd, \( J = 15.8, 6.0 \) Hz, 1H), 2.47 (dd, \( J = 13.9, 6.5, 1.7 \) Hz, 1H), 1.95 (dt, \( J = 14.0, 11.1 \) Hz, 1H) ppm; \textbf{13C NMR} (101 MHz, Chloroform-\( d \)): \( \delta = 169.9, 158.6, 143.1, 137.2, 135.6, 131.3, 128.8 \) (2C), 128.6 (2C), 128.4, 128.2 (2C), 127.7 (2C), 126.8, 124.0, 122.4, 122.1, 121.7, 110.6, 76.3, 66.7, 40.1, 39.8, 39.6 ppm; \textbf{IR} (KBr): \( \nu = 3933, 3892, 3886, 3881, 3871, 3639, 3821, 3807, 3736, 3712, 3690, 3656, 3650, 3638, 3630, 3620, 3063, 3030, 2951, 2922, 2865, 2360, 2343, 2250, 1949, 1611, 1740, 1736, 1689, 1647, 1637, 1596, 1572, 1550, 1493, 1462, 1455, 1438, 1399, 1376, 1352, 1341, 1307, 1283, 1214, 1210, 1156, 1103, 1073, 1030, 1022, 980, 940, 909, 846, 756, 734, 699 \text{ cm}^{-1} \); \textbf{HRMS} (ESI+) \( m/z \): calcd. for \( \text{C}_{26}\text{H}_{21}\text{NaO}_3\text{S}^+ [\text{M+H}]^+ \): 415.1362, found: 415.1365.

**Benzyl** (\( R,E \))-2-((6-(4-methoxyphenyl)-4-phenyl-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetateacetate (10)

S30
To a stirred suspension of 3e (19.5 mg, 0.04 mmol, 1.0 eq.) boronic acid (7.4 mg, 0.05 mmol, 1.2 eq.) and KOAc (15.7 mg, 0.16 mmol, 4.0 eq.) in anhydrous and degassed 1,4-dioxane (0.4 ml) was Pd(dppf)Cl$_2$ (2.9 mg, 0.004 mmol, 0.1 eq.) added in one portion. Reaction mixture was stirred under Ar atmosphere at 105 °C for 24 h. Resulting suspension was filtered through short pad of silica gel (hex / EtOAc – 7:1). Solvents were evaporated in vacuo. Crude product was purified by column chromatography (hex / EtOAc = 15:1), affording the title compound as white solid. (Note: The title compound readily crystallized from boiling hept / i-PrOH – 9:1).

Yield 10 = 48%; ee = 90%: the enantiomeric excess of product was determined by HPLC using chiral HPLC with an IA column (mobile phase: n-heptane/propan-2-ol – 97:3, λ = 256 nm, V = 1.0 ml/min, t = 25 °C) $t_R$ = 18.6 min (major enan.), $t_R$ = 9.7 min (minor enan.); m.p. = 172.7 °C; $[\alpha]_D^{20} = 122.6$ (c = 0.3, CHCl$_3$); $^1$H NMR (400 MHz, Chloroform-d): $\delta = 7.73$ (dd, $J = 8.3$, 0.6 Hz, 1H), 7.43 (dd, $J = 8.3$, 1.8 Hz, 1H), 7.41 – 7.19 (m, 13H), 6.94 (d, $J = 8.7$ Hz, 2H), 5.84 (d, $J = 1.4$ Hz, 1H), 5.12 (q, $J = 12.5$ Hz, 2H), 4.43 (dd, $J = 6.4$, 4.4 Hz, 1H), 4.11 (dd, $J = 15.4$, 4.5 Hz, 1H), 3.85 (s, 3H), 3.40 (ddd, $J = 15.4$, 6.5, 1.6 Hz, 1H) ppm; $^{13}$C NMR (101 MHz, Chloroform-d): $\delta = 166.3$, 165.9, 159.1, 154.0, 141.3, 137.9, 136.7, 136.1, 133.7, 130.1, 128.7 (2C), 128.5 (2C), 128.2 (2C), 128.1, 128.0 (2C), 127.5 (2C), 127.1, 122.7, 122.6, 118.9, 114.2 (2C), 112.5, 101.7, 65.8, 55.3, 36.1, 31.1 ppm; IR (KBr): $\nu = 3025$, 2962, 2932, 2839, 1715, 1658, 1610, 1589, 1539, 1494, 1449, 1356, 1299, 1272, 1254, 1210, 1186, 1156, 1096, 1039, 1024, 988, 961 cm$^{-1}$; HRMS (ESI+) m/z: calcd. for C$_{33}$H$_{26}$NaO$_4$S [M+Na]$^+$: 541.1439, found: 541.1444.
Crystallographic data for 3a and 6b

Crystallographic data for 3a and 6b were collected on Bruker D8 VENTURE Kappa Duo PHOTON100 by μS micro-focus sealed tube either of MoKα (λ= 0.71073) (3a) or Cu Kα (λ= 1.54178 Å) (6b) at a temperature of 120(2) K. The structures were solved by direct methods (XT99) and refined by full matrix least squares based on $F^2$ (SHELXL20189). The hydrogen atoms on carbon were fixed into idealized positions (riding model) and assigned temperature factors $H_{iso}(H) = 1.2 U_{eq}(pivot atom)$. The absolute structure determination was based on anomalous dispersion of sulphur atom.

Crystal data for 3a: $C_{26}H_{20}O_{3}S$, $M_r$ = 412.48; Orthorhombic, $P 2_1 2_1 2_1$ (No 19), $a = 7.9759 (4)$ Å, $b = 16.1628 (8)$ Å, $c = 31.7213 (15)$ Å, $V = 4089.3 (3)$ Å$^3$, $Z = 8$, $D_x = 1.340$ Mg m$^{-3}$, light yellow bar of dimensions $0.37 \times 0.20 \times 0.11$ mm, multi-scan absorption correction ($\mu = 0.18$ mm$^{-1}$) $T_{min} = 0.91$, $T_{max} = 0.98$; a total of 33870 measured reflections ($\theta_{max} = 27.6^\circ$), from which 9441 were unique ($R_{int} = 0.031$) and 8559 observed according to the $I > 2\sigma(I)$ criterion. The refinement converged ($\Delta/\sigma_{max} = 0.001$) to $R = 0.038$ for observed reflections and $wR(F^2) = 0.089$, GOF = 1.09 for 541 parameters and all 9441 reflections. The final difference map displayed no peaks of chemical significance ($\Delta \rho_{max} = 0.28$, $\Delta \rho_{min} -0.30$ e.Å$^{-3}$). Absolute structure parameter (Flack40) -0.02(2).

Crystal data for 6b: $C_{27}H_{21}NO_{3}S$, $M_r$ = 439.51; Orthorhombic, $P 2_1 2_1 2_1$ (No 19), $a = 5.7472 (2)$ Å, $b = 16.9120 (6)$ Å, $c = 22.0104 (8)$ Å, $V = 2139.34 (3)$ Å$^3$, $Z = 4$, $D_x = 1.365$ Mg m$^{-3}$, colourless bar of dimensions $0.40 \times 0.06 \times 0.05$ mm, multi-scan absorption correction ($\mu = 1.59$ mm$^{-1}$) $T_{min} = 0.77$, $T_{max} = 0.93$; a total of 14933 measured reflections ($\theta_{max} = 66.6^\circ$), from which 3770 were unique ($R_{int} = 0.026$) and 3662 observed according to the $I > 2\sigma(I)$ criterion. The refinement converged ($\Delta/\sigma_{max} = 0.001$) to $R = 0.026$ for observed reflections and $wR(F^2) = 0.063$, GOF = 1.08 for 289 parameters and all 3770 reflections. The final difference map displayed no peaks of chemical significance ($\Delta \rho_{max} = 0.13$, $\Delta \rho_{min} -0.24$ e.Å$^{-3}$). Absolute structure parameter (Flack40) -0.008(5).

---

Figure S2. View on one of two symmetrically independent molecule of (R)-3-3a. Displacement ellipsoids are drawn on 50% probability level. The most important difference between A and B molecules is in the conformation of pyrane rings.

Figure S3. View on molecule of (R)-3-6b. Displacement ellipsoids are drawn on 50% probability level.
Figure S4. View on the two overlapping molecules of 3a. The fit as based on atoms S1, C4, C5, C14, C15, C16, C17, C18, C19.

X-ray crystallographic data have been deposited with the Cambridge Crystallographic Data Centre under deposition number CCDC 1916993 and CCDC 1916994 for 3a and 6b, respectively and can be obtained free of charge from the Centre via its website (www.ccdc.cam.ac.uk/getstructures).
NMR spectra
5-Chlorobenzo[b]thiophen-2(3H)-one (11b)
5-Nitrobenzo[b]thiophen-2(3H)-one (11c)
5-Bromobenzo[b]thiophen-2(3H)-one (11e)
6-Bromobenzo[b]thiophen-2(3H)-one (11f)
7-Bromobenzo[b]thiophen-2(3H)-one (11g)
4-Bromobenzo[b]thiophen-2(3H)-one (11h)
3-Benzylidenebenzo[\textit{b}]thiophen-2(3\textit{H})-one (1a) – mixture of \textit{E}/\textit{Z} isomers
(E)-3-Benzylidenebenzo[b]thiophen-2(3H)-one (1a) – pure E isomer
3-Benzyldene-5-chlorobenzothiophen-2(3H)-one (1b)
3-Benzylidene-5-nitrobenzo[b]thiophen-2(3H)-one (1c)
3-Benzylidene-5-methylbenzo[b]thiophen-2(3H)-one (1d)
3-Benzylidene-5-bromobenzo[b]thiophen-2(3H)-one (1e)
3-Benzylidene-6-bromobenzothiophen-2(3H)-one (1f)
3-Benzyldene-7-bromobenzothiophene-2(3H)-one (1g)
3-(4-Chlorobenzylidene)benzo[\textbf{b}]thiophen-2(3H)-one (1h)
4-((2-Oxobenzob[b]thiophen-3(2H)-ylidene)methyl)benzonitrile (1i)
3-(4-(Trifluoromethyl)benzylidene)benzo[b]thiophen-2(3H)-one (1j)
3-(4-Nitrobenzylidene)benzo[b]thiophen-2(3H)-one (1k)
3-(4-Methoxybenzylidene)benzo[b]thiophen-2(3H)-one (11)
3-(4-Methylbenzylidene)benzo[b]thiophen-2(3H)-one (1m)
3-(4-Bromobenzylidene)benzo[b]thiophen-2(3H)-one (1n)
3-(3-Bromobenzylidene)benzo[b]thiophen-2(3H)-one (1o)
3-(2-Bromobenzylidene)benzo[b]thiophen-2(3H)-one (1p)
3-(Furan-3-ylmethylene)benzo[b]thiophen-2(3H)-one (1q)
(E)-3-Butylidenebenzo[b]thiophen-2(3H)-one (1r)
(E)-3-(cyclohexylmethylene)benzo[b]thiophen-2(3H)-one (1s)
Benzyl (R,E)-2-(4-phenyl-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (3a)
Benzyl \((R,E)\)-2-(5-chloro-4-phenyl-3,4-dihydro-2\(H\)-benzo[4,5]thieno[2,3-\(b\)]pyran-2-ylidene)acetate (3b)
Benzyl (R,E)-2-(5-nitro-4-phenyl-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (3c)
Benzyl \((R,E)\)-2-(7-bromo-4-phenyl-3,4-dihydro-2\(H\)-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (3f)
Benzyl \((R,E)\)-2-(8-bromo-4-phenyl-3,4-dihydro-2\(H\)-benzo[4,5]thieno[2,3-\(b\)]pyran-2-ylidene)acetate (3g)
Benzyl \((R,E)\)-2-(4-(4-chlorophenyl)-3,4-dihydro-2\(H\)-benzo[4,5]thieno[2,3-\(b\)]pyran-2-ylidene)acetate (3h)
Benzyl \((R,E)\)-2-(4-(4-nitrophenyl)-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (3k)
Benzyl (R,E)-2-(4-(p-tolyl)-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (3m)
Benzyl (R,E)-2-(4-(4-bromophenyl))-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (3n)
Benzyl \((R,E)\)-2-(4-(2-bromophenyl))-3,4-dihydro-2\(H\)-benzo[4,5]thieno[2,3-\(b\)]pyran-2-ylidene)acetate (3p)
Benzyl \((R,E)\)-2-(4-(furan-3-yl)-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (3q)
Benzyl (S,E)-2-(4-propyl-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (3r)
Benzyl \((R,E)\)-2-(4-cyclohexyl-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (3s)
Methyl (R,E)-2-(4-phenyl-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (3t)
(Z)-4-Benzylidene-2-phenylthiazol-5(4H)-one (5c)
Benzyl (R,E)-2-(2,7-diphenyl-6,7-dihydro-5H-pyran-2,3-d[thiazol-5-ylidene)acetate (6b)
Benzyl (R,E)-2-(2,7-diphenyl-6,7-dihydro-5H-pyra[3,2-d]thiazol-5-ylidene)acetate (6c)
Benzyl (R)-2-(4-phenyl-4H-benzo[4,5]thieno[2,3-b]pyran-2-yl)acetate (4a)
Benzyl 2-\(\{(2S,4R)\}-4\text{-phenyl}-3,4\text{-dihydro}-2\text{H}\text{-benzo}[4,5]\text{-thieno}[2,3-b]\text{pyran}-2\text{-yl}\text{acetateacetate}\ (9)
Benzyl \((R,E)\)-2-(6-(4-methoxyphenyl)-4-phenyl-3,4-dihydro-2H-benzo[4,5]thieno[2,3-b]pyran-2-ylidene)acetate (9)
Chiral HPLC

Conditions: IB column

mobile phase: heptane / i-PrOH – 90:10

$\lambda = 207$ nm, $V = 1.0$ ml/min, $t = 25$ °C

for 3a: $t_R = 5.8$ min (minor), $t_R = 10.0$ min (major).

Method A:

$ee = 90\%$

Method B:

$ee = 99\%$
Conditions: IA column

Mobile phase: heptane / i-PrOH – 97:3

λ = 232 nm, V = 1.0 ml/min, t = 25 °C

For 3b: \( t_R = 10.0 \text{ min (minor), } t_R = 10.7 \text{ min (major).} \)

**Method A:**

\[ ee = 86 \% \]

**Method B:**

\[ ee = 89 \% \]
Conditions: IB column

mobile phase: heptane / i-PrOH – 90:10

\( \lambda = 280 \text{ nm, } V = 1.0 \text{ ml/min, } t = 25 \text{ °C} \)

for 3c: \( t_R = 10.2 \text{ min (major), } t_R = 10.9 \text{ min (minor).} \)

Method A:

\( ee = 80 \% \)

Method B:

\( ee = 80 \% \)
Conditions: IA column

\[ \text{mobile phase: heptane / i-PrOH} \rightarrow 97:3 \]
\[ \lambda = 234 \text{ nm}, \ V = 1.0 \text{ ml/min}, \ t = 25 \ ^\circ \text{C} \]

for 3e: \( t_R = 10.5 \text{ min (minor)}, \ t_R = 11.4 \text{ min (major)} \).

Method A:

\[ ee = 89 \% \]

Method B:

\[ ee = 90 \% \]
**Conditions:** IA column

mobile phase: heptane / i-PrOH – 97:3

\[\lambda = 206 \text{ nm}, V = 1.0 \text{ ml/min}, t = 25 ^\circ C\]

for 3f: \(t_R = 10.1 \text{ min (minor)}, t_R = 11.0 \text{ min (major)}\).

**Method A:**

\[ee = 83\%\]

**Method B:**

\[ee = 87\%\]
Conditions: IA column

mobile phase: heptane / i-ProOH – 97:3

\( \lambda = 206 \text{ nm}, \ V = 1.0 \text{ ml/min}, \ t = 25 ^\circ \text{C} \)

for 3g:  \( t_R = 8.0 \text{ min (minor)}, \ t_R = 8.8 \text{ min (major)} \).

Method A:

\[ ee = 87 \% \]

Method B:

\[ ee = 90 \% \]
Conditions: IB column
mobile phase: heptane / i-PrOH – 90:10
\( \lambda = 254 \, \text{nm}, \, V = 1.0 \, \text{ml/min}, \, t = 25 \, ^\circ \text{C} \)
for 3h: \( t_R = 6.5 \) min (minor), \( t_R = 14.0 \) min (major).

\[

ee = 88 \%
\]

Method A:

\[

ee = 93 \%
\]

Method B:
**Conditions:** IB column

- Mobile phase: heptane / i-PrOH – 80:20
- $\lambda = 254$ nm, $V = 1.0$ ml/min, $t = 25$ °C
- for 3i: $t_R = 10.3$ min (minor), $t_R = 25.4$ min (major).

---

**Method A:**

- $ee = 80\%$

---

**Method B:**

- $ee = 78\%$
Conditions: IB column

- Mobile phase: heptane / i-PrOH – 90:10
- $\lambda = 254$ nm, $V = 1.0$ ml/min, $t = 25$ °C
- For 3j: $t_R = 7.0$ min (minor), $t_R = 17.8$ min (major).

Method A:

$ee = 84\%$

Method B:

$ee = 75\%$
Conditions: IB column

cellule phase: heptane / i-PrOH – 80:20

λ = 254 nm, V = 1.0 ml/min, t = 25 °C

for 3k: t_R = 9.8 min (minor), t_R = 24.2 min (major).

Method A:

ee = 75 %

Method B:

ee = 73 %
**Conditions:** IB column

mobile phase: heptane / i-PrOH – 90:10

\( \lambda = 254 \text{ nm}, \ V = 1.0 \text{ ml/min}, \ t = 25 ^\circ \text{C} \)

for 3I: \( t_R = 7.1 \text{ min (minor), } t_R = 10.8 \text{ min (major).} \)

**Method A:**

\( ee = 85 \% \)

**Method B:**

\( ee = 85 \% \)
**Conditions:** IB column

mobile phase: heptane / i-PrOH – 90:10

$\lambda = 254$ nm, $V = 1.0$ ml/min, $t = 25 \, ^\circ C$

for 3m: $t_R = 5.5$ min (minor), $t_R = 8.9$ min (major).

\[ \text{CO}_2\text{Bn} \]

---

**Method A:**

\[ ee = 89\% \]

**Method B:**

\[ ee = 89\% \]
**Conditions:** IB column  
mobile phase: heptane / i-PrOH – 90:10  
\( \lambda = 254 \text{ nm}, \ V = 1.0 \text{ ml/min}, \ t = 25^\circ \text{C} \)  
for 3n: \( t_R = 7.2 \text{ min (minor)}, \ t_R = 15.2 \text{ min (major)} \).

**Method A:**  
\( ee = 86\% \)

**Method B:**  
\( ee = 90\% \)
Conditions: IB column

mobile phase: heptane / i-PrOH – 80:20

$\lambda = 254$ nm, $V = 1.0$ ml/min, $t = 25$ °C

for 3o: $t_R = 6.2$ min (minor), $t_R = 12.4$ min (major).

Method A:

$ee = 85\%$

Method B:

$ee = 86\%$
**Conditions:** IA column

mobile phase: heptane / i-PrOH – 97:3

$\lambda = 254 \text{ nm}$, $V = 1.0 \text{ ml/min}$, $t = 25 \ ^\circ \text{C}$

for 3p: $t_R = 6.1 \text{ min}$ (major), $t_R = 7.7 \text{ min}$ (minor).

Method A:

$ee = 89\%$

Method B:

$ee = 88\%$
**Conditions:** IB column

mobile phase: heptane / i-PrOH – 90:10

$\lambda = 254$ nm, $V = 1.0$ ml/min, $t = 25$ $^\circ$C

for 3q: $t_R = 6.3$ min (minor), $t_R = 10.6$ min (major).

**Method A:**

$ee = 66\%$

**Method B:**

$ee = 66\%$
**Conditions:** IB column

- mobile phase: heptane / i-PrOH – 90:10
- \( \lambda = 254 \text{ nm} \), \( V = 1.0 \text{ ml/min} \), \( t = 25 ^\circ C \)
- for 3r: \( t_R = 4.6 \text{ min (minor)} \), \( t_R = 5.9 \text{ min (major)} \).

**Method A:**

- ee = 89 %
**Conditions:** IA column

- mobile phase: heptane / i-PrOH – 97:3
- $\lambda = 293$ nm, $V = 1.0$ ml/min, $t = 25^\circ C$
- for 3s: $t_R = 5.0$ min (major), $t_R = 6.0$ min (minor).

**Method A:**

$ee = 89\%$
Conditions: IB column

mobile phase: heptane / i-PrOH – 90:10

$\lambda = 206$ nm, $V = 1.0$ ml/min, $t = 25$ °C

for 3t: $t_R = 5.0$ min (minor), $t_R = 9.1$ min (major).

Method A:

\[ ee = 89 \%
\]

Method B:

\[ ee = 98 \%
\]
Conditions: IB column

mobile phase: heptane / i-PrOH – 90:10

$\lambda = 254$ nm, $V = 1.0$ ml/min, $t = 25 \, ^\circ$C

for 6a: $t_R = 6.2$ min (major), $t_R = 7.2$ min (minor).

\[ \text{Method A:} \] ee = 98 %

\[ \text{Method B:} \] ee = 98 %
Conditions: IB column

mobile phase: heptane / i-PrOH – 80:20

λ = 208 nm, V = 1.0 ml/min, t = 25 °C

for 6b: t_R = 8.7 min (major), t_R = 10.9 min (minor).

Method A:

ee = 98%

Method B:

ee = 99%
Conditions: IB column

- Mobile phase: heptane / i-PrOH – 80:20
- \( \lambda = 210 \text{ nm} \), \( V = 1.0 \text{ ml/min} \), \( t = 25 ^\circ C \)
- for 6c: \( t_R = 5.9 \text{ min} \) (minor), \( t_R = 29.2 \text{ min} \) (major).

Method A:

\[ ee = 87\% \]

Method B:

\[ ee = 98\% \]
Conditions: IB column mobile phase: heptane / i-PrOH – 90:10
$\lambda = 284$ nm, $V = 1.0$ ml/min, $t = 25$ °C
for 4a: $t_R = 7.1$ min (minor), $t_R = 9.7$ min (major).

$ee = 99\%$
**Conditions:** IB column

- Mobile phase: heptane / i-PrOH – 60:40
- λ = 254 nm, V = 1.0 ml/min, t = 25 °C
- for 8: t_R = 8.1 min (minor), t_R = 10.9 min (major).

\[ ee = 99\% \]
Conditions: IB column

mobile phase: heptane / i-PrOH – 90:10

$\lambda = 207$ nm, $V = 1.0$ ml/min, $t = 25$ °C

for 9: $t_R = 9.2$ min (minor), $t_R = 20.0$ min (major).

$ee = 99\%$
Conditions: IA column

mobile phase: heptane / i-PrOH – 97:3

$\lambda = 256$ nm, $V = 1.0$ ml/min, $t = 25$ °C

for 10: $t_R = 18.6$ min (major), $t_R = 9.7$ min (minor).

$ee = 90\%$