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SYNTHESIS OF FUNCTIONALIZED CHROMANES VIA A FORMAL [3 + 3] CYCLOADDITION OF ALLENE SULFONAMIDES TO PHENOLS

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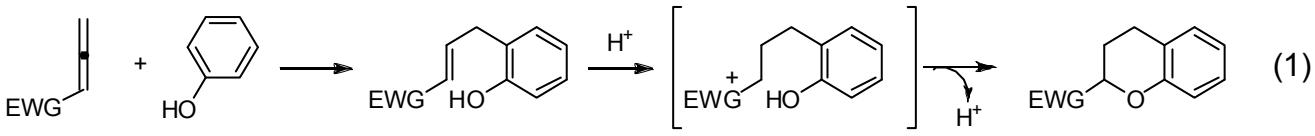
Abstract – The Brønsted acid catalyzed formal [3 + 3] cycloaddition reaction of allene sulfonamides **1** with phenols **2** provides functionalized chromanes. This formal [3 + 3] cycloaddition reaction is proposed to proceed via a stepwise process involving intermolecular hydroarylation followed by intramolecular cyclization.

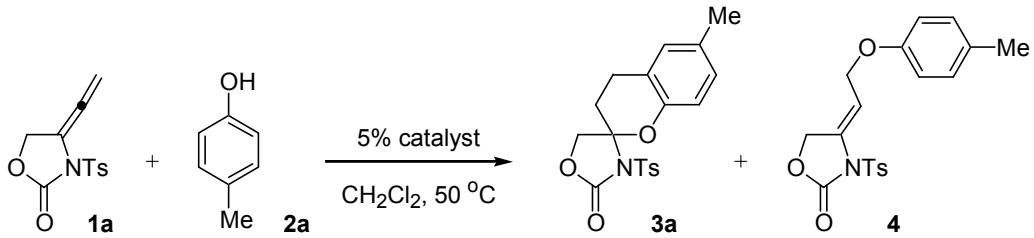
The transition metal catalyzed intramolecular addition of phenolic oxygen nucleophiles to alkenes[1] and the hydroarylation[2] of oxygen-tethered arene-ene substrates are two of the most promising strategies for the synthesis of chromanes, which are of great interest due to their potentially broad range of biological activities.[3] Furthermore, intermolecular reactions, which are an attractive and much simpler strategy for the synthesis of chromanes from commercially available phenols and allylic alcohols[4] or 1,3-dienes,[5] have also been extensively studied. A few approaches for the synthesis of chromanes which do not involve metal based catalysts, such as direct aromatic carbon-oxygen bond formation using tertiary phosphines,[6] amines[7] or Ipy_2BF_4[8] as a catalyst, or stoichiometric amount of hypervalent iodine reagent,[9] have also been reported. However, Brønsted acid catalyzed approaches are particularly rare.[10] We envisioned that regioselective intermolecular hydroarylation at the terminal sp^2 carbon atom of an allene possessing an electron withdrawing group (EWG) with phenols could be a straightforward approach to the direct formation of the corresponding chromanes upon intramolecular addition of the phenolic hydroxy group to the internal allenic double bond (eq. 1). However, selective intermolecular nucleophilic addition to the terminal sp^2 carbon atom rather than the central carbon atom of allenes is usually difficult[11] as the vinyl anion generated is less stable.[12]



(1)

To overcome this problem, we decided to use the easily prepared allene sulfonamides **1**[13] as their terminal sp^2 carbon double bond has been found to behave as an enone toward heteronucleophiles.[13b] Thus, allene sulfonamide **1a** reacts with phenol to form a carbon-oxygen bond at the terminal sp^2 carbon atom of the allene. During the course of our study aimed at the synthesis of chromanes by a formal [3 + 3] cycloaddition reaction as shown in equation (1), we found that addition of a catalytic amount of a Brønsted acid to a mixture of **1a** and *p*-cresol (**2a**; 2.0 equiv) completely suppresses carbon-oxygen bond formation at the terminal sp^2 carbon atom of the allene bond to give **4**, and the only product of the reaction (**3a**) is that resulting from a formal [3 + 3] cycloaddition reaction via a hydroarylation/cyclization pathway (Table 1).

Table 1. Catalyst screening for the synthesis of chromane derivative **3a**[a)]



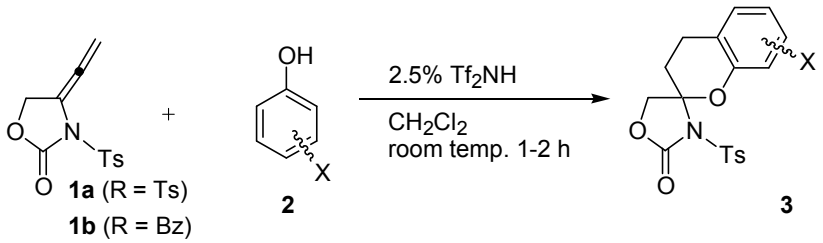
entry	catalyst	time	**3a** (%)	**4** (%)
1	none	2 h	9	55
2	CSA[b)]	12 h	62	0
3	*p*-TsOH[c)]	45 min	67	0
4	TfOH[d)]	<5 min	78	0
5	Tf_2NH[e)]	5 min	82	0
6[f)]	Tf_2NH	60 min	79	0
7[g)]	Tf_2NH	15 min	81	0

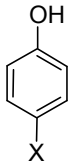
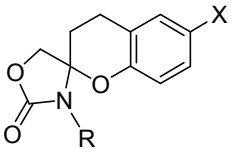
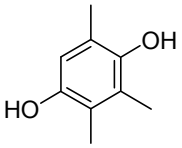
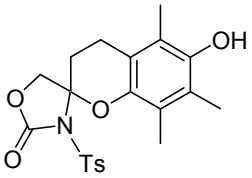
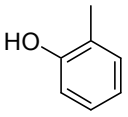
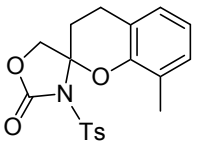
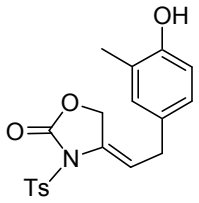
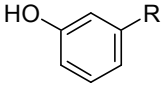
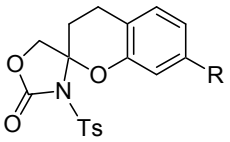
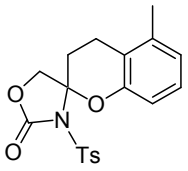
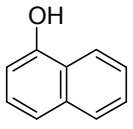
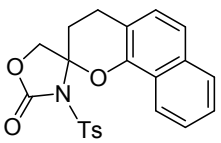
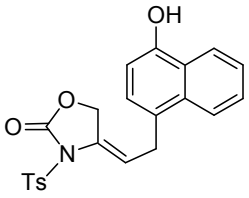
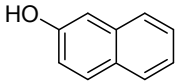
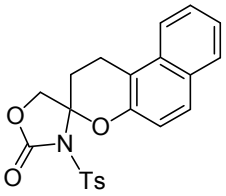
[a)] A mixture of **1a** (1.0 equiv), **2a** (2.0 equiv) and catalyst (0.05 equiv) in CH_2Cl_2 at 50 °C. [b)] Camphor sulfonic acid. [c)] *p*-Toluenesulfonic acid. [d)] Trifluoromethanesulfonic acid. [e)] Trifluoromethanesulfonimde. [f)] 2% of Tf_2NH was used. [g)] Reaction was carried out at room temperature.

We examined several Brønsted acids and found that the reaction rate increased with the acidity of the Brønsted acid (TfOH > Tf_2NH > *p*-TsOH > CSA). The use of a strong Brønsted acid such as trifluoromethanesulfonic acid (TfOH) or trifluoromethanesulfonimide (Tf_2NH) gave the best catalytic activity (entries 4 and 5). Furthermore, the use of Tf_2NH as a catalyst allowed a lower catalyst loading with no effect on the yield of **3a** (entry 6). It should be noted that the reaction could be carried out at room

temperature (entry 7). To the best of our knowledge, there are no reports of the Brønsted acid catalyzed hydroarylation of allenes at room temperature.[14]

Table 2. Formal [3 + 3] cycloaddition of **1a** or **1b** to phenols[a)]



Entry	1	Phenols		Products (%)	
1	**1a**		**2b** (X = OMe)		**3b** (X = OMe, 85)
2	**1a**		**2c** (X = Br)		**3c** (X = Br, 30)
3	**1a**		**2d** (X = I)		**3d** (X = I, 45)
4	**1a**		**2e** (X = Bpin)		**3e** (X = Bpin, 43)
5	**1b**		**2a** (X = Me)		**3f** (X = Me, 79)
6	**1a**		**2f**		**3g** (69)
7	**1a**		**2g**		**3h** (24)
					**5a** (40)
8	**1a**		**2h** (R = Me)		**3i** (R = Me, 36)
9			**2i** (R = OH)		**3k** (R = OH, 59)
					**3j** (15)
10	**1a**		**2j**		**3l** (24)
					**5b** (27)
11	**1a**		**2k**		**3m** (82)

[a)] **1a** or **1b** (1.0 equiv), **2a** (2.0 equiv) and Tf_2NH (0.025 equiv) were used.[15]

Under the optimized reaction conditions in hand, the scope of the reaction was investigated with a variety of functionalized phenols (see Table 2). The reaction feature has turned out to occur dependently of the electronic nature of the substituent on the benzene ring. For example, substrates containing electron donating group afforded the desired products **3b** in excellent yield (entry 1), whereas the presence of an electron withdrawing group resulted in a much longer reaction time and the corresponding products were obtained in only modest yield (entries 2-4). The structure of **3a** was confirmed unequivocally by X-ray diffraction (Figure 1). Likewise, an electron-withdrawing group on the nitrogen of **1a** is essential for the present reaction. Thus, while the use of **1b**, which possesses a benzoyl group on nitrogen, also provided the corresponding chromanes **3f** in high yield (entry 5), changing this substituent to a benzyl group resulted in none of the desired product being obtained. Trimethylhydroquinone (**2f**), which is used in the synthesis of tocopherol,[10] also gave the corresponding chromane **3g** in excellent yield (entry 6). As for asymmetrical substrates, *o*-cresol (**2g**) afforded the desired product **3h** in low yield along with the hydroarylation product **5a** (entry 7). The stereochemistry of **5a** was determined to be *E* by NOE experiments. A similar result was obtained with *m*-cresol (**2h**; entry 8), whereas resorcinol (**2i**) gave **3k** in rather better yield (entry 9). 1-Naphthol (**2j**) also reacted in a similar manner to **2a** to give a mixture of **3l** and **5b** respectively (entry 10). In contrast, the reaction with 2-naphthol (**2k**) afforded the desired tricyclic product **3m** selectively in excellent yield (entry 11).

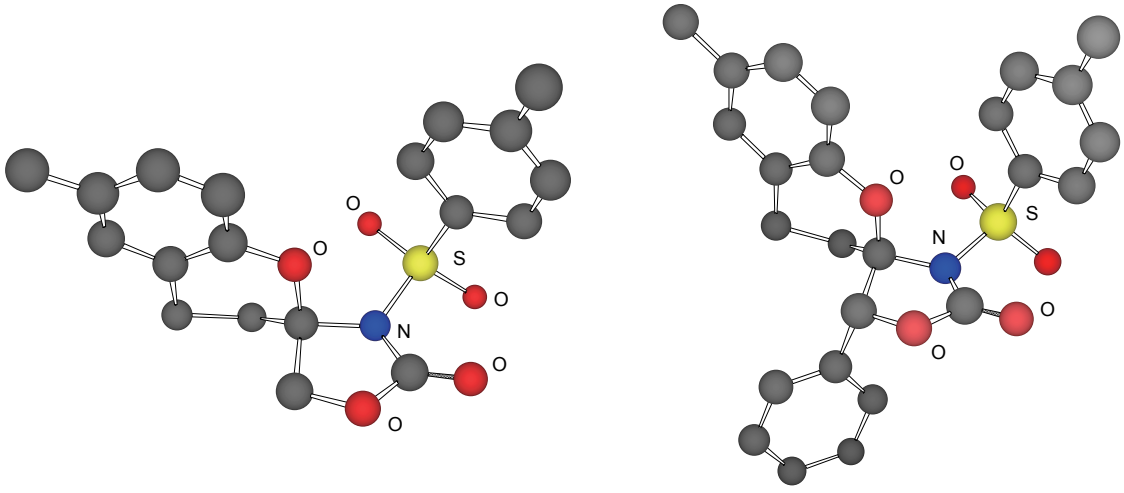
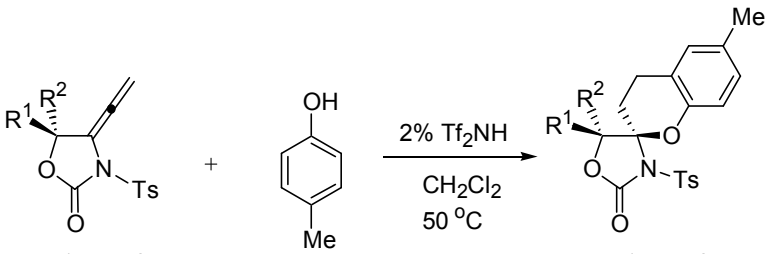


Figure 1. X-Ray structure of **3a** (left, CCDC 739400) and **3n** (right, CCDC 739401).

Interestingly, substrates **1c** and **1d**, which possess a substituent at the C5 position on the 2-oxazolidinone ring, reacted with **2a** to give desired products **3n** and **3o**, respectively, in good to excellent yield (Scheme 1). Compound **3n** was obtained with very high diastereoselectivity, thereby suggesting that a carbocationic intermediate generated via an enamide is involved in the intramolecular addition of the hydroxyl group of **2a** in the second step. The structure of **3n** was also confirmed by X-ray diffraction analysis (Figure 1).



1c (R^1=H, R^2=Ph) **2a** (2.0 equiv.) **3n** (R^1=H, R^2=Ph, 73%, >99:1 dr)
1d (R^1=R^2=Me) **3o** (R^1=R^2=Me, 68%)

Scheme 1. Substituent effects at the C5 position in **1c** and **1d**.

In conclusion, we have demonstrated that allene sulfonamides **1a-d** undergo a formal [3 + 3] cycloaddition with phenols under mild reaction condition in the presence of a catalytic amount of a Brønsted acid to give the corresponding functionalized chromanes in good to excellent yield. This reaction follows a hydroarylation/cyclization pathway and is a rare example of a selective intermolecular hydroarylation at the terminal sp^2 carbon atom of an allenic double bond which does not require the presence of a metal based catalyst. Further work concerning the scope of this reaction is currently underway and will be reported in due course.

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14. The reaction of *N*-benzyl-*N*-(1,2-propadienyl) *p*-toluenesulfonamide, 1-triphenylsilyl-1,2-propadiene or 6-phenyl-1,2-hexadiene with *p*-cresol did not give the desired product under the optimized reaction condition.
15. All melting points were obtained on a YANAKO melting apparatus and are uncorrected. Infrared spectra were recorded on a Perkin Elmer FT/IR PARAGON 1000 spectrometer. The ^{1}H NMR spectra were determined in $CDCl_3$ using $CHCl_3$ as an internal reference with a JEOL α-GX 400 FT NMR. ^{13}C NMR spectra were recorded on a JEOL α-GX 400 spectrometer operating at 100 MHz

with complete proton decoupling and referenced to $CDCl_3$ (77.0 ppm). High resolution mass spectra were taken with a JEOL MStation JMS-700. Unless otherwise noted, all commercial materials were used without purification. TLC analysis of reaction mixture was performed on Merck silica gel 60 F254 TLC plates. Flash chromatography was carried out on Merck 60 silica gel (32-63 μm): **Spiro[6-methyl-3,4-dihydrochroman-2,4'-(3'-*p*-toluensulfonyl)oxazolidin]-2'-one (3a)**: White solid, mp 187.2-187.7 ^{o}C, R_f= 0.62 (50% EtOAc/hexane), purified by column chromatography over silica gel (20% EtOAc/hexane) (82%); IR (KBr) 1085, 1125, 1164, 1193, 1283, 1377, 1498, 1596, 1789 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 2.26 (s, 3H), 2.27 (ddd, *J* = 2.0, 5.6, 13.6 Hz, 1H), 2.46 (s, 3H), 2.73 (ddm, *J* = 5.6, 17.2 Hz, 1H), 2.94 (dm, *J* = 17.2, 1H), 3.28 (dt, *J* = 5.6, 13.6 Hz, 1H), 4.12 (d, *J* = 9.2Hz, 1H), 4.23 (d, *J* = 9.2 Hz, 1H), 6.62 (d, *J* = 8.4 Hz, 1H), 6.94 (s, 1H), 6.98 (d, *J* = 8.4 Hz, 1H), 7.37 (d, *J* = 8.4 Hz, 2H), 8.05 (d, *J* = 8.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 20.5, 21.7, 22.6, 29.2, 73.2, 92.9, 116.9, 119.7, 128.9, 129.2, 129.6, 129.8, 131.4, 135.1, 145.6, 149.5, 152.3; HRMS: (EI) *m/z* Calcd. for $C_{19}H_{19}NO_5S$: 373, Found (relative intensity): 373 (M^+, 100), 155 (71); Anal. Calcd for $C_{19}H_{19}NO_5S$: C, 61.11; H, 5.13; N, 3.75; S, 8.59, Found: C, 61.29; H, 5.17; N, 3.78; S, 8.62. **Spiro[6-methoxyl-3,4-dihydrochroman-2,4'-(3'-*p*-toluensulfonyl)-oxazolidin]-2'-one (3b)**: White solid, mp 190.0-190.8 ^{o}C, R_f= 0.51 (50% EtOAc/hexane), purified by column chromatography over silica gel (20% EtOAc/hexane) (85%); IR (KBr): 1037, 1165, 1217, 1282, 1336, 1497, 1794 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 2.29 (ddd, *J* = 2.0, 5.2, 13.2 Hz, 1H), 2.48 (s, 3H), 2.78 (ddm, *J* = 5.2, 16.8 Hz, 1H), 2.97 (ddd, *J* = 2.0, 5.2, 16.8 Hz, 1H), 3.30 (dt, *J* = 13.2, 5.2 Hz, 1H), 3.77 (s, 3H), 4.14 (d, *J* = 9.6 Hz, 1H), 4.25 (d, *J* = 9.6 Hz, 1H), 6.65 (d, *J* = 2.8 Hz, 1H), 6.67 (d, *J* = 8.8 Hz, 1H), 6.76 (dd, *J* = 2.8, 8.8 Hz, 1H), 7.37 (d, *J* = 8.4 Hz, 2H), 8.05 (d, *J* = 8.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 21.7, 22.9, 29.1, 55.7, 73.0, 92.9, 113.5, 114.5, 117.9, 120.6, 129.2, 129.7, 135.0, 145.5, 145.6, 152.3, 154.5; HRMS: (EI) *m/z* Calcd. for $C_{19}H_{19}NO_6S$: 389.0933, Found: 389.0926. **Spiro[6-bromo-3,4-dihydrochroman-2,4'-(3'-*p*-toluensulfonyl)oxazolidin]-2'-one (3c)**: White solid, mp 201.1-202.0 ^{o}C, R_f = 0.58 (50% EtOAc/hexane), purified by column chromatography over silica gel (20% EtOAc/hexane) (30%); IR (KBr): 1087, 1124, 1164, 1205, 1279, 1378, 1477, 1792 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 2.32 (ddd, *J* = 2.0, 5.6, 13.6 Hz, 1H), 2.48 (s, 3H), 2.78 (ddm, *J* = 5.6, 17.2 Hz, 1H), 2.97 (ddd, *J* = 2.0, 5.6, 17.2 Hz, 1H), 3.30 (dt, *J* = 13.6, 5.6 Hz, 1H), 4.16 (d, *J* = 9.2 Hz, 1H), 4.24 (d, *J* = 9.0 Hz, 1H), 6.64 (d, *J* = 9.2 Hz, 1H), 7.28 (s, 1H), 7.29 (d, *J* = 9.2 Hz, 1H), 7.37 (d, *J* = 8.0 Hz, 2H), 8.03 (d, *J* = 8.0 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 21.8, 22.4, 28.8, 73.1, 92.9, 114.3, 118.9, 122.1, 129.3, 129.7, 131.3, 131.9, 134.9, 145.9, 150.8, 152.0; HRMS: (EI) *m/z* Calcd. for $C_{18}H_{16}BrNO_5S$: 436.9933, Found: 436.9939. **Spiro[6-iodo-3,4-dihydrochroman-2,4'-(3'-*p*-toluensulfonyl)oxazolidin]-2'-one (3d)**: White solid, mp 198.3-199.1 ^{o}C, R_f = 0.55 (50%

EtOAc/hexane), purified by column chromatography over silica gel (20% EtOAc/hexane) (45%); IR (KBr): 1084, 1124, 1164, 1204, 1279, 1376, 1474, 1793 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz): δ 2.29 (ddd, *J* = 2.0, 5.2, 13.2 Hz, 1H), 2.48 (s, 3H), 2.78 (ddm, *J* = 5.2, 16.8 Hz, 1H), 2.97 (ddd, *J* = 2.0, 5.2, 16.8 Hz, 1H), 3.30 (dt, *J* = 5.6, 13.2 Hz, 1H), 4.14 (d, *J* = 9.6 Hz, 1H), 4.25 (d, *J* = 9.6 Hz, 1H), 6.52 (d, *J* = 9.2 Hz, 1H), 7.36 (d, *J* = 8.4 Hz, 1H), 7.45-7.48 (m, 2H), 8.02 (d, *J* = 8.4 Hz, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 21.8, 22.2, 28.7, 73.1, 84.4, 92.9, 119.3, 122.7, 129.3, 129.6, 134.8, 137.1, 137.9, 145.8, 151.6, 152.0; HRMS: (EI) *m/z* Calcd. for $C_{18}H_{16}INO_5S$: 484.9794, Found: 484.9783. **Spiro[6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolanyl)-2,4'-(3'-*p*-toluensulfonyl)-oxazolidin]-2'-one (3e)**: White solid, mp 232.2-235.3 °C, R_f = 0.52 (50% EtOAc/hexane), purified by column chromatography over silica gel (20% EtOAc/hexane) (43%); IR (KBr): 1084, 1164, 1274, 1359, 1795 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz): δ 1.34 (s, 12H) 2.33 (ddd, *J* = 1.6, 5.2, 13.6 Hz, 1H), 2.48 (s, 3H), 2.78 (ddm, *J* = 5.6, 16.8 Hz, 1H), 3.02 (ddd, *J* = 1.6, 4.4, 16.8 Hz, 1H), 3.31 (dt, *J* = 13.6, 5.6 Hz, 1H), 4.16 (d, *J* = 9.6 Hz, 1H), 4.24 (d, *J* = 9.6 Hz, 1H), 6.73 (d, *J* = 8.4 Hz, 1H), 7.37 (d, *J* = 8.4 Hz, 2H), 7.62 (s, 1H), 7.63 (d, *J* = 8.4 Hz, 1H), 8.05 (d, *J* = 8.4 Hz, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 21.8, 22.3, 24.81, 24.84, 29.2, 73.3, 83.8, 93.1, 116.6,, 119.4, 129.3 129.7, 134.9, 135.0, 136.3, 145.7, 152.2, 154.3; HRMS: (EI) *m/z* Calcd. for $C_{24}H_{28}BNO_7S$: 485.1680, Found: 485.1685. **Spiro[6-methyl-3,4-dihydrochroman-2,4'-(3'-benzoyl)oxazolidin]-2'-one (3f)**: White solid, mp 100-100.5 °C, R_f = 0.45 (50% EtOAc/hexane), purified by column chromatography over silica gel (20% EtOAc/hexane) (79%); IR (KBr): 1088, 1126, 1219, 1306, 1340, 1382, 1450, 1498, 1699, 1794 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz): δ 2.16 (ddd, *J* = 2.4, 5.2, 13.2 Hz, 1 H), 2.28 (s, 3 H), 2.81 (ddm, *J* = 5.6, 16.8 Hz, 1 H), 2.96 (ddd, *J* = 2.4, 6.0, 16.8 Hz, 1 H), 3.13 (dt, *J* = 6.0, 13.2 Hz, 1H), 4.27 (d, *J* = 9.2 Hz, 1 H), 4.42 (d, *J* = 9.2 Hz, 1 H), 6.82 (d, *J* = 8.4 Hz, 1 H), 6.93 (s, 1H), 6.98 (d, *J* = 8.4 Hz, 1H), 7.45 (t, *J* = 7.6 Hz, 2H), 7.58 (d, *J* = 7.6 Hz, 1H), 7.71 (d, *J* = 7.6 Hz, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 20.5, 22.4, 26.9, 73.1, 117.4, 119.6, 128.1, 128.8, 129.1, 129.3, 131.0, 132.9, 133.7, 149.9, 153.7, 169.3; HRMS: (EI) *m/z* Calcd. for $C_{19}H_{17}NO_4$: 323.1158, Found: 323.1153. **Spiro[5,7,8-trimethyl-6-hydroxy-3,4-dihydrochroman-2,5'-(3'-*p*-toluensulfonyl)oxazolidin]-2'-one (3g)**: White solid, mp 196.2-197.0 °C, R_f = 0.50 (50% EtOAc/hexane), purified by column chromatography over silica gel (20% EtOAc/hexane) (69%); IR (KBr): 1087, 1160, 1278, 1371, 1456, 1636, 1788, 2924, 3566 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz): δ 1.89 (s, 3H), 2.13 (s, 3H), 2.15 (s, 3H), 2.34 (ddd, *J* = 1.6, 6.0, 13.2 Hz, 1H), 2.46 (s, 3H), 2.58 (ddm, *J* = 6.0, 16.8 Hz, 1H)), 2.99 (dd, *J* = 5.2, 16.8 Hz, 1H), 3.28 (dt, *J* = 6.0, 13.2 Hz, 1H), 4.10 (d, *J* = 9.6 Hz, 1H), 4.29 (d, *J* = 9.6 Hz, 1H), 4.40 (brs, 1H), 7.34 (d, *J* = 8.4 Hz, 1H), 8.08 (d, *J* = 8.4 Hz, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 11.5, 11.9, 12.2, 21.3, 21.7, 29.2, 72.3, 92.7, 116.5, 118.6, 122.3, 123.2, 129.3, 129.6, 135.2, 143.5, 145.5, 146.4, 152.5; HRMS: (EI) *m/z* Calcd. for

$C_{21}H_{23}NO_6S$: 417.1246, Found 417.1235. **Spiro[8-methyl-3,4-dihydrochroman-2,4'-(3'-*p*-toluensulfonyl)oxazolidin]-2'-one (3h)** : White solid, mp 161.0-162.0 ^oC, R_f = 0.51 (50% EtOAc/hexane), purified by column chromatography over silica gel (20% EtOAc/hexane) (24%); IR (KBr): 1086, 1125, 1163, 1280, 1376, 1468, 1794 cm^{-1}; ^1H NMR ($CDCl_3$, 400 NHz): δ 2.03 (s, 3H), 2.33 (ddd, *J* = 1.6, 5.6, 13.2 Hz, 1H), 2.46 (s, 3H), 2.79 (ddm, *J* = 5.6, 17.2 Hz, 1H), 3.03 (ddd, *J* = 1.6, 5.6, 17.2 Hz, 1H), 3.32 (dt, *J* = 5.6, 13.2 Hz, 1H), 4.16 (d, *J* = 9.6 Hz, 1H), 4.25 (d, *J* = 9.6 Hz, 1H), 6.87 (t, *J* = 7.2 Hz, 1H), 6.97 (d, *J* = 7.2 Hz, 1H), 7.02 (d, *J* = 7.2 Hz, 1H), 7.35 (d, *J* = 8.0 Hz, 2H), 8.09 (d, *J* = 8.0 Hz, 2H).^{13}C NMR ($CDCl_3$, 100 MHz): δ 15.8, 21.7, 22.8, 29.1, 73.1, 93.1, 119.6, 121.6, 126.77, 126.80, 129.3, 129.5, 129.6, 135.2, 145.6, 149.9, 152.3; HRMS: (EI) *m/z* Calcd. for $C_{19}H_{19}NO_5S$: 373.0984, Found: 373.0987. **Spiro[7-methyl-3,4-dihydrochroman-2,4'-(3'-*p*-toluensulfonyl)oxazolidin]-2'-one (3i)**: Isolated as an inseparable mixture of **3j**; white solid, R_f = 0.42 (50% EtOAc/hexane), purified by column chromatography over silica gel (20% EtOAc/hexane) (36%); IR (KBr): 1084, 1121, 1180, 1281, 1377, 1458, 1792 cm^{-1}; ^1H NMR ($CDCl_3$, 400 NHz): δ 2.27-2.33 (m, 1 H), 2.31 (s, 3H), 2.49 (s, 3H), (ddm, *J* = 5.2, 16.4 Hz, 1H), 2.96 (dm, *J* = 16.4 Hz, 1H), 3.29 (dt, *J* = 5.6, 13.6 Hz, 1H), 4.15 (d, *J* = 9.6 Hz, 1H), 4.26 (d, *J* = 9.6 Hz, 1H), 6.57 (s, 1H), 6.78 (d, *J* = 7.6 Hz, 1H), 7.01 (d, *J* = 7.6 Hz, 1H), 7.38 (d, *J* = 8.4 Hz, 2H), 8.07 (d, *J* = 8.4 Hz, 2H); HRMS: (EI) *m/z* Calcd. for $C_{19}H_{19}NO_5S$: 373.0984, Found: 373.0988. **Spiro[5-methyl-3,4-dihydrochroman-2,4'-(3'-*p*-toluensulfonyl)oxazolidin]-2'-one (3j)**: Isolated as an inseparable mixture of **3i**; white solid, R_f = 0.42 (50% EtOAc/hexane), purified by column chromatography over silica gel (20% EtOAc/hexane) (15%): ^1H NMR ($CDCl_3$, 400 NHz): δ 2.27-2.33 (m, 1 H), 2.31 (ddm, *J* = 5.2, 16.4 Hz, 1H), 2.96 (dm, *J* = 16.4 Hz, 1H), 3.29 (dt, *J* = 5.6, 13.6 Hz, 1H), 4.15 (d, *J* = 9.6 Hz, 1H), 4.26 (d, *J* = 9.6 Hz, 1H), 6.57 (s, 1H), 6.78 (d, *J* = 7.6 Hz, 1H), 7.01 (d, *J* = 7.6 Hz, 1H), 7.38 (d, *J* = 8.4 Hz, 2H), 8.07 (d, *J* = 8.4 Hz, 2H). **Spiro[7-hydroxy-3,4-dihydrochroman-2,4'-(3'-*p*-toluensulfonyl)oxazolidin]-2'-one (3k):** White solid, mp 215.3-216.1 ^oC, R_f = 0.34 (50% EtOAc/hexane), purified by column chromatography over silica gel (20% EtOAc/hexane) (59%); IR (film): 1084, 1163, 1272, 1366, 1456, 1624, 1782, 3465 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz): δ 2.29 (ddd, *J* = 2.0, 5.2, 13.6 Hz, 1H), 2.47 (s, 3H), 2.70 (ddm, *J* = 5.2, 16.8 Hz, 1H), 2.92 (ddm, *J* = 5.2, 16.8 Hz, 1H), 3.28 (dt, *J* = 6.0, 13.6 Hz, 1H), 4.15 (d, *J* = 9.6 Hz, 1H), 4.26 (d, *J* = 9.6 Hz, 1H), 6.25 (d, *J* = 2.4 Hz, 1H), 6.47 (dd, *J* = 2.4, 8.4 Hz, 1H), 6.97 (d, *J* = 2.4 Hz, 1H), 7.36 (d, *J* = 8.4 Hz, 1H), 8.05 (d, *J* = 8.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 21.7, 21.9, 29.3, 73.2, 93.0, 103.8, 109.8, 112.1, 129.3, 129.7, 130.0, 135.0, 145.7, 152.3, 152.5, 155.8; HRMS: (EI) *m/z* Calcd. for $C_{18}H_{17}NO_6S$: 375.0777, Found: 375.0777. **Spiro[3,4-dihydrobenzo[h]chroman-2,4'-(3'-*p*-toluensulfonyl)oxazolidin]-2'-one (3l)** : White solid, mp 214.7-215.3 ^oC, R_f= 0.50 (50% EtOAc/hexane), purified by column chromatography over

silica gel (20% EtOAc/hexane) (24%); IR (film) 1085, 1160, 1280, 1372, 1457, 1508, 1542, 1791, 2924, 3566 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz): δ 2.44 (ddd, *J* = 2.0, 6.0, 13.6 Hz, 1H), 2.53 (s, 3H), 2.94 (ddm, *J* = 5.6, 13.6, 16.8 Hz, 1H), 3.13 (ddd, *J* = 2.0, 6.0, 16.8 Hz, 1H), 3.45 (dt, *J* = 6.0, 13.6 Hz, 1H), 4.20 (d, *J* = 9.6 Hz, 1H), 4.30 (d, *J* = 9.6 Hz, 1H), 7.20 (d, *J* = 8.0 Hz, 1H), 7.27-7.42 (m, 3H), 7.45-7.51 (m, 2H), 7.61 (d, *J* = 8.4 Hz, 1H), 7.79 (d, *J* = 8.4 Hz, 1H), 8.14 (dm, *J* = 8.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 21.8, 22.9, 28.9, 73.0, 93.4, 114.2, 121.2, 121.7, 124.8, 125.6, 126.3, 126.7, 127.6, 129.5, 129.8, 133.4, 135.2, 145.7, 146.3, 152.5; HRMS: (EI) *m/z* Calcd. for $C_{22}H_{19}NO_5S$: 409.0984, Found 409.0982. **Spiro[3,4-dihydrobenzo[f]chroman-2,4'-(3'-*p*-toluensulfonyl)oxazolidin]-2'-one (3m)** : White solid, mp 234.2-235.3 °C, R_f = 0.53 (50% EtOAc/hexane), purified by column chromatography over silica gel (20% EtOAc/hexane) (82%); IR (KBr): 1084, 1164, 1280, 1378, 1596, 1793 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz): δ 2.49 (s, 3H), 2.50 (m, 1H), 2.90 (m, 1H), 3.41-3.50 (m, 2H), 4.24 (d, *J* = 10.0 Hz, 1H), 4.29 (d, *J* = 10.0 Hz, 1H), 6.94 (d, *J* = 8.8 Hz, 1H), 7.39-7.45 (m, 2H), 7.56 (dt, *J* = 1.2, 8.0 Hz, 1H), 7.71 (d, *J* = 8.8 Hz, 1H), 7.81-7.83 (m, 2H), 8.11 (d, *J* = 8.4 Hz, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 19.5, 21.8, 28.8, 72.8, 92.7, 112.4, 118.3, 122.0, 124.4, 127.1, 128.6, 129.1, 129.3, 129.5, 129.8, 132.2, 135.0, 145.7, 149.1, 152.3; HRMS: (EI) *m/z* Calcd. for $C_{22}H_{19}NO_5S$: 409.0984, Found: 409.0978. **Spiro[6-methyl-3,4-dihydrochroman-2,4'-(5'-phenyl-3'-*p*-toluensulfonyl)oxazolidin]-2'-one (3n)**: White solid, mp 188.9-189.6 °C, R_f= 0.65 (50% EtOAc/hexane), purified by column chromatography over silica gel (20% EtOAc/hexane) (73%); IR (KBr): 1070, 1164, 1379, 1498, 1790 cm^{-1}; ^1H NMR (CDCl3, 400 MHz): δ 1.99 (ddd, *J* = 2.0, 5.6, 14.0 Hz, 1H), 2.30 (s, 3 H), 2.38 (ddm, *J* = 6.0, 17.2 Hz, 1H), 2.49 (s, 3H), 2.56 (ddd, *J* = 2.0, 6.0, 17.2 Hz, 1H), 3.18 (dt, *J* = 6.0, 13.6 Hz, 1H), 5.21 (s, 1H), 6.67 (d, *J* = 8.4 Hz, 1H), 6.89 (s, 3H), 7.00 (d, *J* = 8.4 Hz, 1H), 7.30 (dd, *J* = 1.6, 8.0 Hz, 2H), 7.35-7.47 (m, 5H), 8.07 (d, *J* = 8.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 20.5, 21.8, 21.9, 25.5, 85.3, 96.1, 116.9, 120.2, 127.8, 128.7, 129.0, 129.2, 129.6, 129.9, 130.3, 130.5, 133.0, 135.1, 145.6, 149.4, 152.6; HRMS: (EI) *m/z* Calcd. for $C_{25}H_{23}NO_5S$: 449.1297, Found: 449.1291. **Spiro[6-methyl-3,4-dihydrochroman-2,4'-(5',5'-dimethyl-3'-*p*-toluensulfonyl)oxazolidin]-2'-one (3o)**: White solid, mp 185.2-185.9 °C, R_f = 0.60 (50% EtOAc/hexane), purified by column chromatography over silica gel (20% EtOAc/hexane) (68%); IR (film): 899, 922, 991, 1085, 1174, 1221, 1276, 1350, 1376, 1453, 1497, 1596, 1784, 2924 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 1.22 (s, 3 H), 1.52 (s, 3 H), 2.28 (s, 3 H), 2.40 (ddd, *J* = 2.8, 4.8, 14.0 Hz, 1 H), 2.47 (s, 3 H), 2.70 (ddm, *J* = 5.2, 16.8 Hz, 1H), 2.94 (ddd, *J* = 2.4, 5.6, 16.8 Hz, 1H), 3.42 (dt, *J* = 6.0, 14.0 Hz, 1 H), 6.60 (d, *J* = 8.4 Hz, 1 H), 6.91 (s, 1H), 6.98 (d, *J* = 8.4 Hz, 1 H), 7.33 (d, *J* = 8.4 Hz, 2H), 7.99 (d, *J* = 8.4 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.5, 21.7, 22.8, 22.9, 23.4, 24.8, 87.2, 97.2, 115.6, 119.9, 128.9, 129.0, 129.4, 129.9, 130.9, 135.3, 145.4, 150.9; HRMS: (EI) *m/z* Calcd. for $C_{21}H_{23}NO_5S$:

401.1297, Found: 401.1295. **(*E*)-3-(*p*-Toluenesulfonyl)-4-(2-*p*-tolyloxyethylidene)-oxazolidin-2-one (4)**: White solid, mp 104.2-105.0 °C, R_f = 0.52 (50% EtOAc/hexane), purified by column chromatography over silica gel (20% EtOAc/hexane) (55%); IR (film): 1088, 1160, 1278, 1378, 1456, 1509, 1542, 1783, 2923 cm^{-1}; ^1H NMR($CDCl_3$, 400 MHz): δ 2.30 (s, 3H), 2.46 (s, 3H), 4.52 (dt, *J* = 5.6, 1.2 Hz, 2H), 4.94 (dt, *J* = 2.4, 1.2 Hz, 2H), 6.30 (tt, *J* = 2.4, 5.6 Hz, 1H), 6.77 (d, *J* = 8.0, 2H), 7.09 (d, *J* = 8.0 Hz, 2H), 7.94 (d, *J* = 8.0 Hz, 2H); ^{13}C NMR($CDCl_3$,100 MHz): δ 20.5, 21.7, 63.6, 66.1, 102.3, 114.5, 128.3, 129.9, 130.0, 130.1, 130.9, 134.2, 146.3, 151.5, 155.7; HRMS: (EI) *m/z* Calcd. for $C_{22}H_{19}NO_5S$: 373.0984, Found: 373.0985. **(*E*)-4-[2-(4-Hydroxy-3-methylphenyl)-ethylidene]-3-(*p*-toluenesulfonyl)-oxazolidin-2-one (5a)**: Yellow solid, mp 115.1-116.5 °C, R_f = 0.29 (50% EtOAc/hexane), purified by column chromatography over silica gel (20% EtOAc/hexane) (40%); ^1H NMR($CDCl_3$, 400 MHz): δ 2.23 (s, 3H), 2.46 (s, 3H), 3.17 (d, *J* = 8.0 Hz, 2H), 4.78 (s, 1H), 4.82 (m, 2H), 6.16 (tt, *J* = 2.4, 8.0 Hz, 1H), 6.71 (d, *J* = 8.0 Hz, 1H), 6.84 (dm, *J* = 8.0 Hz, 1H), 6.88 (s, 1H), 7.34 (d, *J* = 8.4 Hz, 2H), 7.93 (d, *J* = 8.4 Hz, 2H); ^{13}C NMR($CDCl_3$,100 MHz): δ 15.8, 21.7, 31.9, 65.7, 106.9, 115.1, 124.1, 126.5, 128.2, 128.6, 129.9, 130.60, 130.64, 134.3, 146.1, 151.9, 152.6; HRMS: (EI) *m/z* Calcd. for $C_{19}H_{19}NO_5S$: 373.0984, Found: 373.0986. **(*E*)-4-[2-(4-Hydroxy-1-naphthalenyl)-ethylidene]-3-(*p*-toluenesulfonyl)-oxazolidin-2-one (5b)**: White solid, mp 112.5-113.5 °C, R_f = 0.60 (50% EtOAc/hexane), purified by column chromatography over silica gel (20% EtOAc/hexane) (27%); IR (film): 1086, 1163, 1267, 1373, 1457, 1508, 1542, 1771, 3567 cm^{-1}; ^1H NMR($CDCl_3$, 400 MHz): δ 2.44 (s, 3H), 3.61 (d, *J* = 7.2 Hz, 2H), 4.79 (m, 2H), 4.82 (m, 2H), 5.44 (brs, 1H), 6.29 (tt, *J* = 2.8, 7.2 Hz, 1H), 6.75 (d, *J* = 7.6 Hz, 1H), 7.10 (d, *J* = 7.6 Hz, 1H), 7.28 (dm, *J* = 8.0 Hz, 2H), 7.52-7.57 (m, 2H), 7.82 (m, 1H), 7.87 (d, *J* = 8.6 Hz, 1H), 8.27 (m, 1H); ^{13}C NMR($CDCl_3$,100 MHz): δ 21.7, 29.8, 65.7, 106.5, 107.9, 122.6, 123.3, 124.9, 125.2, 125.5, 126.8, 126.9, 128.1, 128.9, 129.9, 132.6, 134.2, 146.1, 150.9, 151.9; HRMS: (EI) *m/z* Calcd. for $C_{22}H_{19}NO_5S$: 409.0984, Found: 409.0984. **X-Ray Crystal Strucutuer Analysis of Compound 3a (CCDC 739400)**[16]: $C_{19}H_{19}NO_5S$, M_r = 373.42 g/mol, colorless plate, crystal size 0.40 x 0.40 x 0.40 mm, monoclinic, space group $P2_1/c$ (#), a = 9.223(8) Å, b = 12.854(10) Å, c = 15.780(8) Å, α = 90°, β = 105.43(5)°, γ = 90°, V = 1803(2) $Å^3$, T = 296 K, Z = 4, D_{calc} = 1.375 g/cm^3, λ = 0.71069 Å, F(000) = 784, μ(Mo–K_α) = 2.09 cm^{-1}, 5799 measured reflections, 4114 reflections with $I > 0.00\sigma(I)$, 235 parameters, R = 0.156, wR = 0.091, residual electron density +0.48 / -0.43 e $Å^{-3}$. **X-Ray Crystal Strucutuer Analysis of Compound 3n (CCDC 739401)** [16]: $C_{25}H_{23}NO_5S$, M_r = 449.52 g/mol, colorless prismatic, crystal size 0.20 x 0.20 x 0.30 mm, orthorhombic, space group Pbca (#61) a = 20.654(6) Å, b = 17.908(6) Å, c = 11.846(5) Å, α = 90°, β = 105.43(5)°, γ = 90°, V = 4381(4) $Å^3$, T = 296 K, Z = 84, D_{calc} = 1.363

g/cm^3, $\lambda = 0.71069$ Å, F(000) = 1888.00, μ(Mo–K$_\alpha$) = 1.85 cm^{-1},7044 measured reflections, 1804 reflections with $I > 3.00\sigma(I)$, 289 parameters, R = 0.047, wR = 0.061, residual electron density +0.16 / -0.20 e Å^{-3}.

16. Crystallographic data for the structures in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication number CCDC 739400 and CCDC 739401. Copies of the data can be obtained, free of charge, on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK [fax: +44(0) 1223 336033 or e-mail: deposit@ccdc.cam.ac.uk].