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Benzofuran and indole synthesis *via* Cu(I)-catalyzed coupling of *N*-tosylhydrazone and *o*-hydroxy or *o*-amino phenylacetylene†

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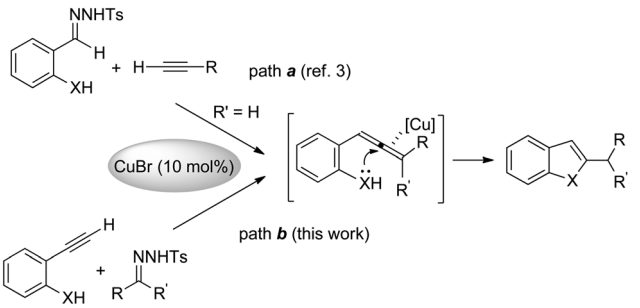
A general and practical method to synthesize 2-substituted benzofurans and indoles is described. This method employs easily accessible *N*-tosylhydrazones and *o*-hydroxy or *o*-amino phenylacetylenes as substrates. The reaction proceeds through a CuBr-catalyzed coupling–allenylation–cyclization sequence under ligand-free conditions.

1. Introduction

Benzofurans and indoles are important structural motifs of a wide range of natural substances, compounds of pharmaceutical interest and commodity chemicals.[1,2] We have previously communicated a new method for the synthesis of benzofurans by a ligand-free CuBr-catalyzed sequential coupling–allenylation–cyclization of salicyl *N*-tosylhydrazones and terminal alkynes.[3] In this reaction, a di-substituted allene intermediate is formed *via* the migratory insertion of a copper carbene species,[4,5] which smoothly undergoes copper-catalyzed intramolecular cyclization to afford 2-substituted benzofurans and indoles (Scheme 1, path ***a***).[6]

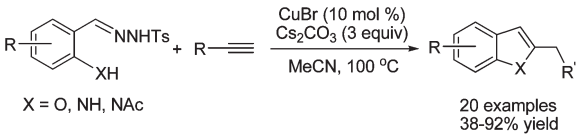
However, the substituents on the benzofurans generated from the salicyl *N*-tosylhydrazones and terminal alkynes are limited to primary benzyl or alkyl groups at the 2-position, which significantly restricts the application of this method in organic synthesis. We note that similar di-substituted or tri-substituted allene intermediates could be formed from *o*-hydroxy or *o*-amino phenylacetylene with various *N*-tosylhydrazones (Scheme 1, path ***b***). In this paper, we report the extension of our study along this line, which in combination with the previous communication constitutes a general and synthetically useful procedure for the synthesis of benzofurans and indoles under copper-catalyzed ligand-free conditions.[7,8]



Scheme 1 CuBr-catalyzed 2-substituted benzofurans and indoles synthesis.

2. Results and discussion

In our preliminary communication, salicyl *N*-tosylhydrazones, which are easily available from the corresponding aldehydes, are reacted with a series of terminal alkynes with CuBr as the catalyst in the presence of Cs_2CO_3 as the base (eqn (1)). A wide range of functional groups are found to tolerate the reaction conditions and 2-substituted benzofurans and indoles can be obtained in good yields. In view of the advantages of this transformation over the previous methods for benzofuran and indole synthesis, we decided to further expand this reaction by employing *o*-hydroxy or *o*-amino phenylacetylene and various *N*-tosylhydrazones as substrates.



(1)

The initial studies have been carried out using phenyl *N*-tosylhydrazone **1a** and *o*-hydroxy phenylacetylene **2a** as the substrates in the presence of CuBr (10 mol%) and Cs_2CO_3 (3 equiv.) in MeCN at 100 °C (Scheme 2). This is the optimized

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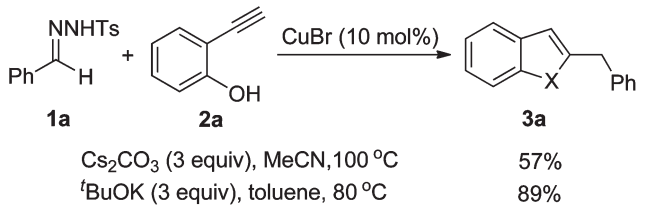
†Electronic supplementary information (ESI) available. See DOI: 10.1039/c2ob26867a



Scheme 2 Fine-tuning of the reaction conditions.

reaction conditions for our previous synthesis of benzofurans. Under such conditions, the desired product **3a** was obtained in 57% yield. Further fine-tuning of the reaction conditions has revealed that ^{t}BuOLi is more effective than other inorganic bases, such as K_2CO_3, NaOAc and ^{t}BuOK. In contrast to the previous observations on the CuBr-catalyzed coupling of salicyl *N*-tosylhydrazones and terminal alkynes, the non-polar solvent toluene was found to be favourable at 80 °C. Under the new reaction conditions, the isolated yield of **3a** could be improved to 89%.

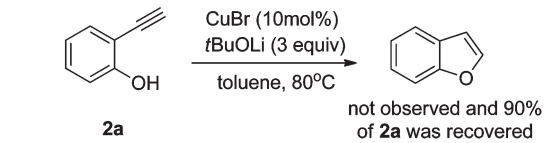
The optimized conditions were then applied to a series of *N*-tosylhydrazones **1a–i** derived from aldehydes with different electronic properties (Table 1). In all cases, the expected benzofurans were isolated in good to excellent yields. The *N*-tosylhydrazones bearing *ortho*-, *para*-, and *meta*-substituents on the phenyl ring all worked well in this reaction. The electronic properties of the substituents do not affect the efficacy of the reaction (Table 1, entries 1–8). It is noteworthy that alkyl *N*-tosylhydrazone **1i** is also effective, affording the desired benzofuran **3i** in 78% (Table 1, entry 9). In this case, the reaction was carried out at 120 °C by using DMSO as the solvent because of the sluggish reaction under the standard conditions. The reaction proceeded equally well with Ts protected 2-aminophenylacetylene, which gave indole **3j** in a yield of 78% (Table 1, entry 10). In another case, when Ac protected 2-aminophenylacetylene **2b** was employed as the substrate, a deprotected indole **3k** was isolated in 81% yield (Table 1, entry 11).

Next, we proceeded to extend this methodology to the construction of secondary alkyl substituted benzofurans and indoles, which are more challenging compounds to synthesize *via* transition metal-catalyzed cross-coupling reactions.[9] Our initial studies using *o*-hydroxy phenylacetylene **2a** and *N*-tosylhydrazone **4a** have shown that the same catalytic system employed in Table 1 only affords the desired benzofuran **5a** in 51% yield (Table 2, entry 1). A slight modification of the reaction conditions revealed MeCN was a better solvent than toluene, in which the desired product **5a** was generated in a yield of 79%. This reaction also proceeded smoothly with other substituted *N*-tosylhydrazones **4b**, **4c** and **4d**. The reaction is not affected by the substituents on the phenyl ring of *N*-tosylhydrazones (Table 2, entries 2 and 4), while a slightly diminished yield was observed when an electron-donating group OMe was introduced (Table 2, entry 3). *N*-Tosylhydrazones derived from butyrophenone, cyclopropyl phenyl ketone and 1,2-diphenylethanone are effective, affording the desired benzofurans **5e–g** in good yields (Table 2, entries 5–7).

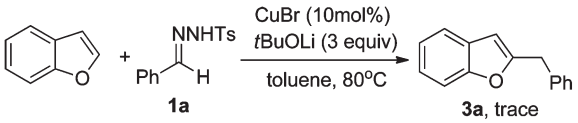
Moreover, cyclic *N*-tosylhydrazone **4h**, which is derived from 4-chromanone, also undergoes smooth reaction with **2a** to afford the corresponding benzofuran **5h** in 76% yield (Table 2, entry 8). This catalytic system has also been applied to the reaction of **2a** with *N*-tosylhydrazones derived from aliphatic ketones **4j** and **4k**. To our delight, the corresponding products **5j** and **5k** could be obtained in 73% and 62% yields using DMSO as the solvent at 120 °C (Table 2, entries 10 and 11). Finally, we checked the possibility of assembling 2-substituted indoles using our process. When Ac protected 2-aminophenylacetylene **2b** was reacted with *N*-tosylhydrazone **4a**, a deprotected indole **5l** was obtained in a yield of 71% (Table 2, entry 12). In another case, treatment of Ts protected 2-aminophenylacetylene **2c** with *N*-tosylhydrazone **4c** yielded protected indole **5m** in 85% (Table 2, entry 13).

As shown in Scheme 1, the key step in this Cu-catalyzed transformation has been proposed as the migratory insertion of Cu carbene species, followed by protonation to afford the allene intermediate. However, transition metal-catalyzed cyclization of 2-ynlphenol or 2-ynlaniline to give benzofuran or indole is a well-established process.[10] Therefore, an alternative mechanism, which involves Cu-catalyzed cyclization followed by a direct Cu carbene insertion into the C–H bond of heterocycles, cannot be strictly eliminated.[11]

To gain insight into the mechanism of this reaction, two control experiments have been performed as shown in eqn (2) and (3). First, **2a** was heated under standard condition for 20 h in the absence of *N*-tosylhydrazone. No benzofuran could be observed and 90% of **2a** was recovered (eqn (2)). Next, benzofuran and *N*-tosylhydrazone **1a** were treated under standard conditions for 4 h. This experiment resulted in a complex mixture, and only a trace amount of the desired product **3a** could be detected by GC-MS (eqn (3)). These results indicate that the pathway involving cyclization–Cu carbene insertion seems less likely for the CuBr-catalyzed reaction described in this paper.



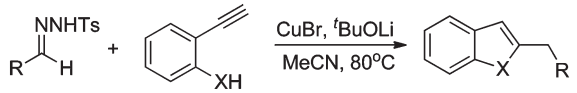
(2)



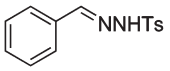
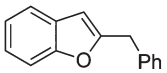
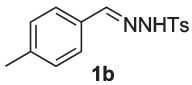
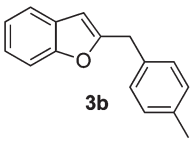
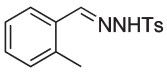
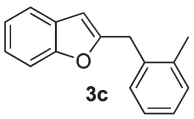
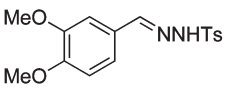
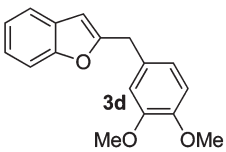
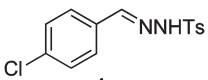
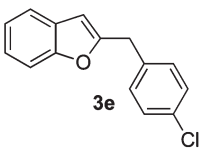
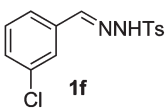
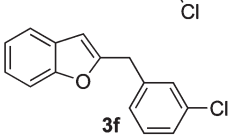
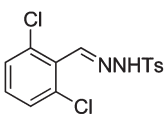
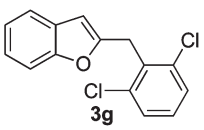
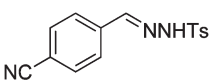
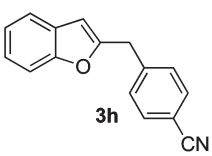
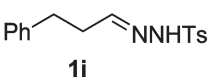
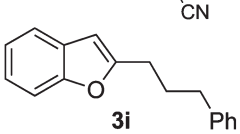
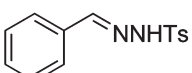
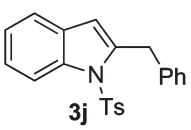
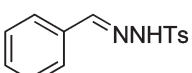
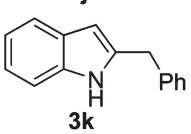
(3)

The mechanism for this reaction is proposed in Scheme 3.[12] First, *in situ* generated diazo compound **B** from *N*-tosylhydrazone is dediazonized by copper acetylide **A**, leading to the formation of the copper carbene species **C**. Migratory insertion of the carbenic carbon to the alkynyl group affords intermediate **D**. The allene **E** is then formed by protonation of intermediate **D**, followed by the copper promoted intramolecular cyclization to give intermediate **G**. Finally, protonation of intermediate **G** gives the benzofuran or indole product and regenerated Cu(I) catalyst.

Table 1 CuBr-catalyzed reactions of *o*-hydroxy or *o*-amino phenylacetylene **2** with *N*-tosylhydrazones derived from aldehydes[a]

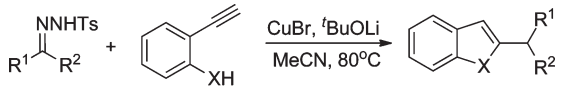


1 **2a**: X=O; **2b**: X=NAc; **2c**:X=NTs **3a-k**

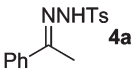
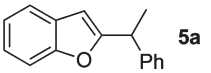
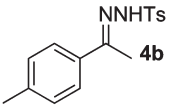
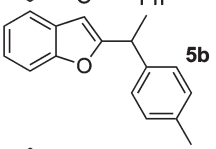
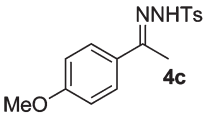
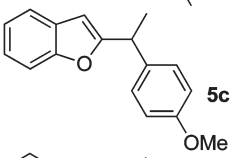
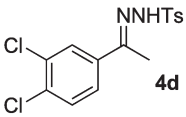
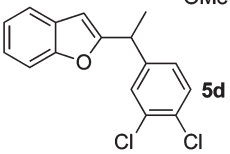
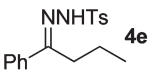
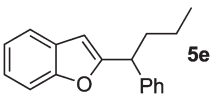
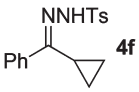
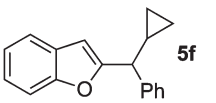
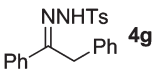
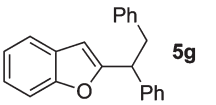
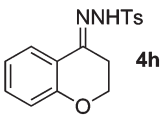
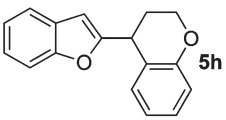
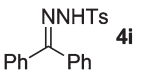
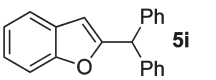
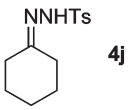
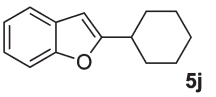
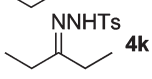
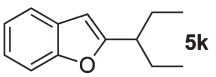
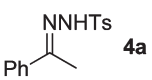
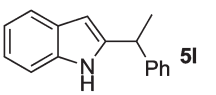
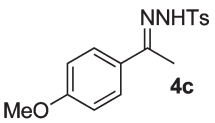
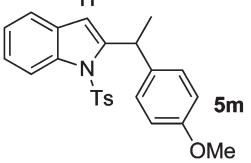
Entry	Hydrazone	Alkyne	Product	Yield[b] (%)
1	 **1a**	**2a**	 **3a**	89
2	 **1b**	**2a**	 **3b**	84
3	 **1c**	**2a**	 **3c**	92
4	 **1d**	**2a**	 **3d**	77
5	 **1e**	**2a**	 **3e**	95
6	 **1f**	**2a**	 **3f**	87
7	 **1g**	**2a**	 **3g**	81
8	 **1h**	**2a**	 **3h**	88
9[c]	 **1i**	**2a**	 **3i**	78
10	 **1a**	**2c**	 **3j**	78
11	 **1a**	**2b**	 **3k**	81

[a] Reaction conditions: *N*-tosylhydrazone **1** (0.33 mmol), alkyne **2** (0.3 mmol), CuBr (10 mol%), ^{t}BuOLi (0.9 mmol), toluene (2 mL), 80 °C, 8 h. [b] Isolated yield. [c] The reaction was carried out by using DMSO as the solvent at 120 °C for 12 h.

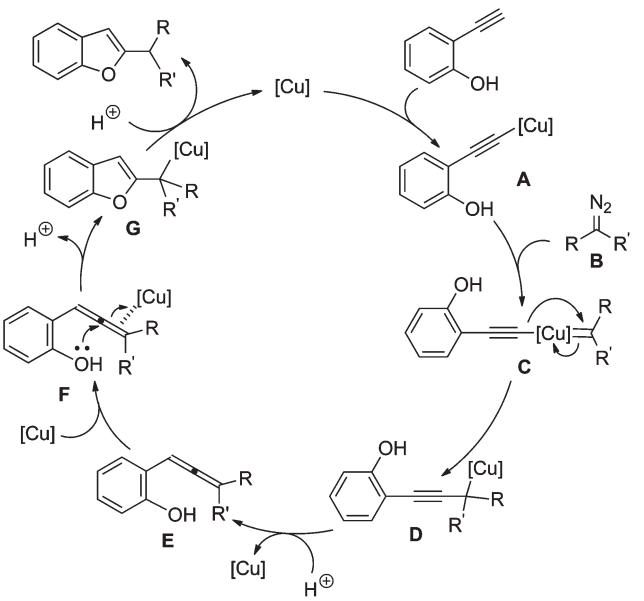
Table 2 CuBr-catalyzed reactions of **2a–c** with *N*-tosylhydrazones derived from ketones[a]



4 **2a**: X=O; **2b**: X=NAc; **2c**:X=NTs **5a-k**

Entry	Hydrazone	Alkyne	Product	Yield[b] (%)
1	 **4a**	**2a**	 **5a**	79(51[c])
2	 **4b**	**2a**	 **5b**	82
3	 **4c**	**2a**	 **5c**	62
4	 **4d**	**2a**	 **5d**	85
5	 **4e**	**2a**	 **5e**	74
6	 **4f**	**2a**	 **5f**	77
7	 **4g**	**2a**	 **5g**	82
8	 **4h**	**2a**	 **5h**	76
9	 **4i**	**2a**	 **5i**	88
10[d]	 **4j**	**2a**	 **5j**	73
11[d]	 **4k**	**2a**	 **5k**	62
12	 **4a**	**2b**	 **5l**	71
13	 **4c**	**2c**	 **5m**	85

[a] Reaction conditions: *N*-tosylhydrazone **4** (0.33 mmol), alkyne **2** (0.3 mmol), CuBr (10 mol%), ^{t}BuOLi (0.9 mmol), MeCN (2 mL), 80 °C, 8 h. [b] Isolated yield. [c] Toluene was used as the solvent. [d] The reaction was carried out by using DMSO as the solvent at 120 °C for 12 h.



Scheme 3 Mechanistic studies.

3. Conclusions

In conclusion, we have further developed the method for the synthesis of 2-substituted benzofurans and indoles *via* the CuBr-catalyzed coupling–allenylation–cyclization of *ortho*-hydroxy or amino phenylacetylene with *N*-tosylhydrazones. A variety of secondary alkyl substituted benzofurans, which are unable to access by our previously reported copper-catalyzed coupling from salicyl *N*-tosylhydrazones and terminal alkyne, can be obtained in good to excellent yields.

4. Experimental section

General procedure for the CuBr-catalyzed synthesis of 2-substituted benzofurans and indoles

CuBr (4.2 mg, 10 mol%), ^{t}BuOLi (0.9 mmol, 72 mg) and *N*-tosylhydrazone (0.33 mmol) were suspended in toluene (2 mL) in a 10 mL Schlenk tube under nitrogen. Then, 2-ethynylphenol (0.3 mmol) was added. The solution was stirred at 80 °C for 8 h. After cooling to room temperature, the resulting mixture was filtered through a short path of silica gel, eluting with hexane and CH_2Cl_2. The volatile compounds were removed *in vacuo* and the crude residue was purified by column chromatography (SiO_2, hexane).

The following known compounds were characterized by comparing their ^{1}H NMR and ^{13}C NMR to the reported values: **3a**,[3] **3b**,[3] **3i**,[3] **3k**,[3] **5a**,[13] **5b**,[14] **5c**,[15] **5i**,[3] **5j**,[16] **5l**.[17]

2-Benzylbenzofuran (3A). ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.12 (s, 2H), 6.38 (s, 1H), 7.18–7.34 (m, 7H), 7.38–7.48 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 35.4, 103.6, 111.2, 120.6, 122.7, 123.7, 127.0, 128.7, 128.9, 129.1, 137.4, 155.1, 158.0.

2-(4-Methylbenzyl)benzofuran (3B). ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.37 (s, 3H), 4.09 (s, 2H), 6.38 (s, 1H), 7.06–7.26 (m, 6H), 7.40–7.49 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 21.5, 35.0, 103.5, 111.5, 120.6, 122.7, 123.5, 128.9, 129.0, 129.5, 134.3, 136.5, 155.1, 158.3. MS (70 eV): *m*/*z* (%): 222 (100) $[M]^+$, 207 (68), 178 (26), 131 (27).

2-(2-Methylbenzyl)benzofuran (3C). IR (film) 743.6, 1174.0, 1252.6, 1374.5, 1454.0, 1511.1, 2853.3, 2925.6 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.38 (s, 3H), 4.12 (s, 2H), 6.26 (s, 1H), 7.21–7.30 (m, 6H), 7.42–7.50 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 19.8, 33.1, 103.5, 111.1, 120.5, 122.5, 123.5, 126.7, 127.3, 129.0, 130.0, 130.6, 135.6, 136.8, 155.0, 157.7; EI-MS (*m*/*z*, relative intensity): 222 (M^+, 100), 207 (35), 178 (35), 131 (37), 107 (85); HRMS (ESI) calcd for $C_{16}H_{15}O$ (M + H^+) 223.1117, found: 223.1109.

2-(3,4-Dimethoxybenzyl)benzofuran (3D). IR (film) 669.4, 746.3, 806.0, 1029.3, 1141.2, 1256.3, 1454.3, 1514.1, 2924.5 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.88 (s, 6H), 4.07 (s, 2H), 6.38 (s, 1H), 6.84 (m, 3H), 7.20–7.26 (m, 2H), 7.41–7.49 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 35.0, 56.2, 103.4, 111.1, 111.5, 112.4, 120.6, 121.2, 122.7, 123.6, 129.0, 129.9, 148.0, 149.2, 155.1, 158.2; EI-MS (*m*/*z*, relative intensity): 268 (M^+, 100), 253 (24), 237 (68), 221 (27), 181 (10), 165 (12), 149 (11), 131 (13); HRMS (ESI) calcd for $C_{17}H_{17}O_3$ (M + H^+) 269.1173, found: 267.1175.

2-(4-Chlorobenzyl)benzofuran (3E). IR (film) 749.6, 797.4, 1016.1, 1091.9, 1225.4, 1454.1, 1491.4, 1513.8, 2924.4 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.09 (s, 2H), 6.39 (s, 1H), 7.20–7.36 (m, 5H), 7.40–7.50 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 34.7, 103.8, 111.2, 120.7, 122.8, 123.8, 128.9, 130.1, 130.4, 132.8, 135.9, 155.1, 157.2; EI-MS (*m*/*z*, relative intensity): 242 (M^+, 100) (Cl^{35}), 244 (M^+, 34) (Cl^{37}) 207 (48), 178 (58), 131 (46), 103 (12), 89 (37); HRMS (EI) calcd for $C_{15}H_{11}ClO$ (M^+) 242.0493, found: 242.0491.

2-(3-Chlorobenzyl)benzofuran (3F). IR (film) 749.8, 799.1, 1015.9, 1091.9, 1254.5, 1454.0, 1593.0, 2924.5 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.10 (s, 2H), 6.43 (s, 1H), 7.20–7.31 (m, 5H), 7.39–7.51 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 35.0, 104.0, 111.2, 1120.0, 120.7, 128.9, 129.2, 130.0, 134.6, 139.4, 155.2, 156.8; EI-MS (*m*/*z*, relative intensity): 242 (M^+, 100) (Cl^{35}), 244 (M^+, 31) (Cl^{37}), 207 (36), 178 (48), 152 (8), 131 (62), 103 (9), 89 (24); HRMS (EI) calcd for $C_{15}H_{11}ClO$ (M^+) 242.0493, found: 242.0492.

2-(2,6-Dichlorobenzyl)benzofuran (3G). IR (film) 748.3, 763.4, 953.4, 1089.4, 1167.8, 1254.4, 1436.6, 1563.0, 2925.4 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.47 (s, 2H), 6.26 (s, 1H), 7.14–7.24 (m, 3H), 7.34–7.45 (m, 4H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 31.0, 103.5, 111.2, 120.6, 122.7, 123.7, 128.5, 128.9, 133.5, 136.3, 154.9; EI-MS (*m*/*z*, relative intensity): 276 (M^+, 100) (Cl^{35}, Cl^{35}), 278 (M^+, 62) (Cl^{35}, Cl^{37}), 280 (M^+, 12) (Cl^{37}, Cl^{37}), 279 (16), 280 (12), 241 (25), 205 (12), 178 (17), 151 (8), 131 (29), 102 (4); HRMS (ESI) calcd for $C_{20}H_{17}O_2$ (M + H^+) 289.1223, found: 289.1217. HRMS (ESI) calcd for $C_{15}H_{11}Cl_2O$ (M + H^+) 277.0182, found: 277.0187.

4-(Benzofuran-2-ylmethyl)benzonitrile (3H). IR (film) 749.9, 811.8, 951.4, 1095.2, 1253.2, 1454.0, 1607.0, 2228.8 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.17 (s, 2H), 6.46 (s, 1H), 7.19–7.27 (m, 2H), 7.31–7.43 (m, 3H), 7.48–7.52 (m, 1H), 7.57–7.62 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 35.4, 104.4, 111.2, 111.9,

119.8, 120.9, 123.0, 124.1, 129.6, 129.8, 132.6, 142.9, 155.2, 155.8; EI-MS (*m*/*z*, relative intensity): 233 (M^+, 100), 204 (27), 176 (9), 149 (34), 131 (73), 116 (5), 102 (9); HRMS (ESI) calcd for $C_{16}H_{12}NO$ (M + H^+) 234.0916, found: 234.0913.

2-(3-Phenylpropyl)benzofuran (3i). ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.10–2.16 (m, 2H), 2.73–2.85 (m, 4H), 6.41 (s, 1H), 7.21–7.31 (m, 7H), 7.42–7.51 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 28.3, 29.7, 35.6, 102.4, 110.9, 120.4, 122.6, 123.3, 126.1, 128.6, 128.7, 129.1, 141.9, 154.8, 159.2.

2-Benzyl-1-tosyl-1*H*-indole (3j). IR (film) 675.3, 748.3, 811.6, 1091.1, 1174.9, 1255.9, 1371.2, 1453.4, 2924.0 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.34 (s, 3H), 4.36 (s, 2H), 6.1 (s, 1H), 7.12–7.15 (m, 2H), 7.18–7.30 (m, 6H), 7.34–7.38 (m, 2H), 7.51–7.55 (m, 2H), 8.14–8.16 (d, *J* = 8.4 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 21.9, 35.6, 111.1, 114.9, 120.5, 123.7, 124.2, 126.6, 126.8, 128.7, 128.9, 129.6, 129.9, 136.3, 137.4, 138.2, 141.2, 144.8; EI-MS (*m*/*z*, relative intensity): 361 (M^+, 86), 205 (100), 178 (11), 91 (17); HRMS (ESI) calcd for $C_{22}H_{20}NO_2S$ (M + H^+) 362.1209, found: 362.1218.

2-Benzyl-1*H*-indole (3k). ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.15 (s, 2H), 6.34 (s, 1H), 7.07–7.16 (m, 2H), 7.24–7.37 (m, 6H), 7.55–7.58 (m, 1H), 7.78 (s, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 35.1, 101.3, 110.7, 119.9, 120.2, 126.9, 128.9, 129.0, 136.5, 138.0, 138.7.

2-(1-Phenylethyl)benzofuran (5a). ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.72 (d, *J* = 7.2 Hz, 3H), 4.26 (q, *J* = 7.2 Hz, 1H), 6.44 (s, 1H), 7.17–7.40 (m, 8H), 7.47–7.51 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 20.8, 40.1, 102.4, 111.3, 120.7, 122.7, 123.7, 126.9, 127.7, 128.8, 129.8, 143.5, 155.0, 162.3; MS (70 eV): *m*/*z* (%): 222 (39) $[M]^+$, 207 (100), 194 (17), 165 (18), 118 (9).

2-(1-*p*-Tolylethyl)benzofuran (5b). ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.70 (d, *J* = 7.2 Hz, 3H), 4.23 (q, *J* = 7.2 Hz, 1H), 6.44 (s, 1H), 7.13–7.20 (m, 6H), 7.38–7.50 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 20.8, 21.5, 39.6, 102.2, 111.2, 120.6, 122.6, 123.6, 127.6, 128.9, 129.5, 136.5, 140.5, 154.9, 162.5. MS (70 eV): *m*/*z* (%): 236 (33) $[M]^+$, 221 (100), 205 (4), 178 (23), 115 (9).

2-(1-(4-Methoxyphenyl)ethyl)benzofuran (5c). ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.70 (d, *J* = 7.2 Hz, 3H), 3.81 (s, 3H), 4.19–4.24 (m, 1H), 6.42 (s, 1H), 6.86–6.89 (m, 2H), 7.16–7.23 (m, 4H), 7.38–7.50 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 20.8, 39.2, 55.6, 102.1, 111.2, 114.8, 120.6, 122.6, 123.6, 128.6, 128.9, 135.6, 154.9, 158.5, 162.6; MS (70 eV): *m*/*z* (%): 252 (27) $[M]^+$, 237 (100), 222 (7), 194 (18), 165 (18), 118 (9).

2-(1-(3,4-Dichlorophenyl)ethyl)benzofuran (5d). IR (film) 726.3, 747.6, 804.1, 1030.6, 1091.8, 1256.4, 1453.4, 1467.0, 2924.3 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.70 (d, *J* = 6.9 Hz, 3H), 4.23 (q, *J* = 6.9 Hz, 1H), 6.49 (s, 1H), 7.11–7.14 (m, 1H), 7.19–7.29 (m, 2H), 7.38–7.42 (m, 3H), 7.52–7.55 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 20.5, 30.1, 102.8, 111.3, 120.9, 122.9, 124.0, 127.2, 128.6, 129.7, 130.7, 131.0, 132.8, 143.7, 155.0, 160.7; EI-MS (*m*/*z*, relative intensity): 290 (M^+, 36) (Cl^{35}), 293 (M^+, 98) $[M]^+(Cl^{37})$, 292 (20), 277 (55), 275 (100), 205 (12), 176 (11), 145 (10); HRMS (EI) calcd for $C_{16}H_{12}Cl_2O$ (M^+) 290.0260, found: 290.0259.

2-(1-Phenylbutyl)benzofuran (5e). IR (film) 745.0, 750.2, 771.0, 1253.8, 1454.3, 2929.8, 2937.8 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.97 (t, *J* = 6.9 Hz, 3H), 1.93–2.05 (m, 1H), 2.17–2.28 (m, 1H), 4.08 (t, *J* = 7.2 Hz 1H), 6.46 (s, 1H), 7.18–7.31 (m, 7H), 7.39–7.50 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 14.3, 21.2, 37.0, 102.5, 111.2, 120.6, 122.6, 122.6, 123.5, 126.9, 128.2, 128.7, 128.9, 142.3, 154.9, 161.5; EI-MS (*m*/*z*, relative intensity): 250 (M^+, 27), 207 (100), 178 (37), 152 (5); HRMS (EI) calcd for $C_{18}H_{18}O$ $[M]^+$ 250.1352, found: 250.1355.

2-(Cyclopropyl(phenyl)methyl)benzofuran (5f). IR (film) 698.4, 740.9, 798.0, 1019.9, 1169.5, 1254.9, 1453.9, 2924.4 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.40–0.48 (m, 2H), 0.67–0.70 (m, 1H), 0.75–0.78 (m, 1H), 1.47–1.53 (m, 1H), 3.43 (d, *J* = 9.3 Hz, 1H), 6.65 (s, 1H), 7.20–7.23 (m, 2H), 7.27–7.35 (m, 5H), 7.39–7.42 (m, 1H), 7.53–7.56 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 5.0, 5.7, 16.1, 50.5, 103.2, 111.3, 120.7, 122.7, 123.6, 127.1, 128.2, 128.7, 128.9, 141.9, 155.1, 161.1; EI-MS (*m*/*z*, relative intensity): 248 (M^+, 68), 220 (100), 207 (40), 191(19), 178 (52), 152 (13), 144 (92), 115 (15); HRMS (ESI) calcd for $C_{18}H_{17}O$ (M+H^+) 249.1274, found: 249.1277.

2-(1,2-Diphenylethyl)benzofuran (5g). IR (film) 297.6, 749.3, 802.5, 1255.1, 1453.7, 1494.7, 2924.0 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.29–3.36 (m, 1H), 3.62–3.69 (m, 1H), 4.43 (t, *J* = 7.5 Hz, 1H), 6.51 (s, 1H), 7.10–7.13 (m, 2H), 7.19–7.33 (m, 10H), 7.47–7.54 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 41.4, 48.2, 103.4, 111.3, 120.8, 122.8, 123.7, 126.5, 126.8, 127.1, 128.4, 128.5, 128.7, 129.3, 139.6, 141.5, 154.9, 160.3; EI-MS (*m*/*z*, relative intensity): 298 (M^+, 5), 207 (100), 178 (33), 152 (6), 105 (8); HRMS (ESI) calcd for $C_{22}H_{19}O$ (M + H^+) 299.1431, found: 299.1433.

4-(Benzofuran-2-yl)chroman (5h). IR (film) 698.7, 750.6, 801.7, 1017.5, 1256.5, 1453.5, 2853.9, 2927.8 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.31–2.49 (m, 2H), 4.16–4.31 (m, 2H), 4.37 (t, *J* = 5.1 Hz, 1H), 6.30 (s, 1H), 6.88–6.94 (m, 2H), 7.15–7.29 (m, 4H), 7.44–7.50 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 27.6, 35.2, 63.6, 105.2, 111.3, 117.47, 120.9, 121.2, 122.9, 123.9, 124.6, 128.7, 128.8, 130.8, 155.1, 160.9; EI-MS (*m*/*z*, relative intensity): 250 (M^+, 100), 235 (9), 221 (45), 165 (11), 131 (15); HRMS (ESI) calcd for $C_{17}H_{15}O_2$ (M + H^+) 251.1067, found: 251.1065.

2-Benzhydrylbenzofuran (5i). ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.62 (s, 1H), 6.30 (s, 1H), 7.18–7.37 (m, 12H), 7.42–7.50 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 51.7, 105.9, 111.4, 120.9, 122.8, 123.9, 127.2, 128.7, 128.8, 129.1, 141.2, 155.3, 160.0; MS (70 eV): *m*/*z* (%): 284 (45) $[M]^+$, 207 (100), 178 (33).

2-Cyclohexylbenzofuran (5j). ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.29–1.59 (m, 4H), 1.76–1.89 (m, 4H), 2.14–1.17 (m, 1H), 6.36 (s, 1H), 7.16–7.29 (m, 2H), 7.38–7.52 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 26.3, 26.5, 31.7, 37.9, 100.0, 110.9, 120.5, 122.5, 123.2, 129.1, 154.5, 164.2; MS (70 eV): *m*/*z* (%): 200 (58) $[M]^+$, 185 (5), 171 (13), 157 (100), 144 (33), 131 (35), 115 (14).

2-(Pentan-3-yl)benzofuran (5k). IR (film) 740.7, 749.9, 797.4, 1008.3, 1251.4, 1454.5, 2853.9, 2927.8 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.91 (t, *J* = 6.6 Hz, 6H), 1.73–1.78 (m, 4H), 2.65 (t, *J* = 6.1 Hz, 1H), 6.39 (s, 1H), 7.18–7.26 (m, 2H), 7.41–7.48 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 12.2, 26.8, 43.2, 102.5, 111.0, 120.6, 122.5, 123.1, 129.1, 154.7, 162.2; EI-MS (*m*/*z*, relative intensity): 188 (M^+, 24), 159 (100), 144 (12), 131

(43), 115 (12), 91 (7); HRMS (EI) calcd for $C_{13}H_{16}O$ $[M]^+$ 188.1196, found: 188.1192.

2-(1-Phenylethyl)-1*H*-indole (5l). ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.75 (d, J = 6.6 Hz, 3H), 4.26 (q, J = 6.9 Hz, 1H), 6.45 (s, 1H), 7.11–7.37 (m, 8H), 7.35–7.70 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 21.7, 39.6, 99.8, 110.7, 119.9, 120.3, 121.6, 127.0, 127.8, 128.7, 128.9, 136.4, 143.2, 144.8; MS (70 eV): m/z (%): 221 (58) $[M]^+$, 206 (100), 179 (15), 144 (10), 102 (13).

2-(1-(4-Methoxyphenyl)ethyl)-1-tosyl-1*H*-indole (5m). IR (film) 671.3, 749.3, 809.3, 1034.0, 1090.9, 1173.1, 1245.8, 1369.9, 1510.8, 2924.3 cm^{-1}; ^{1}H NMR (75 MHz, $CDCl_3$) δ 1.68 (d, J = 6.9 Hz, 3H), 2.30 (s, 3H), 3.79 (s, 3H), 4.98 (q, J = 7.2 Hz, 8H), 6.55–6.79 (m, 2H), 7.02–7.11 (m, 4H), 7.23–7.36 (m, 4H), 7.45–7.48 (m, 1H), 8.17 (d, J = 8.1 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 21.9, 24.2, 30.1, 55.6, 109.5, 113.9, 115.4, 120.6, 123.7, 124.3, 026.5, 128.9, 129.7, 129.9, 136.3, 136.9, 137.6, 144.4, 146.7, 158.3; EI-MS (m/z, relative intensity): 405 (M^+, 50), 390 (17), 271 (39), 249 (73), 234 (100), 149 (60); HRMS (ESI) calcd for $C_{24}H_{24}NO_3S$ ($M + H^+$) 406.1471, found: 406.1474.

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