t-BuOK Mediated Oxidative Coupling Amination of 1,4-Naphthoquinone and Related 3-Indolynaphthoquinones with Amines

Yu Dong, Ting Mei, Qi-Qi Luo, Qiang Feng, Bo Chang, Fan Yang, Hong-wei Zhou, Zhi-Chuan Shi, Ji-Yu Wang, and Bing He

a College of Chemistry and Life Science, Institute of Functional Molecules, Chengdu Normal University, Chengdu, 611130, PR China.
b Southwest Minzu University, Chengdu 610041, P. R. China.
c Chengdu Institute of Organic Chemistry, Chinese Academy of Sciences, Chengdu 610041, P. R. China.

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1. General information

Chemicals and analytical grade solvents were purchased from commercial suppliers and used without further purification unless otherwise stated. All reagents were weighed and handled in air at room temperature. Analytical thin–layer chromatography was performed on glass plates of Silica Gel GF–254 with detection by UV light (254 and 365 nm). Column chromatography was carried out on silica gel (200-300 mesh). $^1$H NMR spectra were recorded at 400 MHz and $^{13}$C NMR spectra were recorded at 101 MHz by using Agilent 400 MHz NMR spectrometer. Chemical shifts were calibrated using residual undeuterated solvent as an internal reference ($^1$H NMR: CDCl$_3$ 7.26 ppm, DMSO-$d_6$ 2.50 ppm, $^{13}$C NMR: CDCl$_3$ 77.16 ppm, DMSO-$d_6$ 39.52 ppm). Data are reported as follows: chemical shift, multiplicity (s = singlet, br s = broad singlet, d = doublet, t = triplet, q = quartet, m = multiplet), Coupling constants ($J$) were reported in Hertz (Hz). HRMS were performed on a Thermo Scientific LTQ Orbitrap XL instrument. Melting points were measured with micro melting point apparatus.

2. Preparation of the starting materials

For this study, N-Protected indoles were prepared from substituted indoles with iodomethane.$^1$ Indoles-substituted 1,4-naphthoquinones (1) were prepared from N-Protected indoles with 1,4-naphthoquinones.$^2$
3. General procedure for the synthesis of the compounds

To a solution of indolynaphthoquinone, phenynaphthoquinones or 1,4-naphthoquinone (0.3 mmol), t-BuOK (0.6 mmol, 2 equiv) in DMF (2 mL) was added amines 2 (0.6 mmol, 2 equiv). The reaction mixture was stirred at room temperature under air atmosphere for 2 h. After the completion of the reaction (monitored by TLC), the reaction was quenched with saturated salt water (8 ml) and the mixture was extracted with EtOAc (3 × 3 mL). The organic extracts were washed with brine, dried over Na$_2$SO$_4$, filtered and the solvent was removed in vacuo. The crude product was purified by silica gel column chromatography to give 3 or 5.

To a solution of the 2-amino-3-indolynaphthoquinones derivatives 3 (0.3 mmol), t-BuOK (0.45 mmol, 1.5 equiv) in DMF (2 mL) was added CoCl$_2$ (0.009 mmol, 3 mol %), The reaction mixture was stirred at 120 °C under air atmosphere for 24 h. After the completion of the reaction (monitored by TLC), and cooled down to room temperature. The reaction was quenched with saturated salt water (8 ml) and the mixture was extracted with EtOAc (3 × 3 mL). The organic extracts were washed with brine, dried over Na$_2$SO$_4$, filtered and the solvent was removed in vacuo. The crude product was purified by silica gel column chromatography to give 6.

4. Optimization of reaction conditions

Table S1. Optimization of base$^a$

| Base   | Yield (%) |
|--------|-----------|
| NaH    | 50        |
| LiHMDS | 60        |
| t-BuOK | 70        |

$^a$Reaction conditions: 1a (0.3 mmol), 2a (0.3 mmol), 10 mol % of catalyst in DMF, 6 h, r.t.
| Entry | Base       | Catalyst | Yield<sup>b</sup> |
|-------|------------|----------|-------------------|
| 1     | t-BuOK     | No       | 53                |
| 2     | K₂CO₃      | No       | NR                |
| 3     | NaHCO₃     | No       | NR                |
| 4     | KOH        | No       | 31                |
| 5     | NaOH       | No       | 33                |
| 6     | CH₃ONa     | No       | NR                |
| 7     | Cs₂CO₃     | No       | NR                |
| 8     | Et₃N       | No       | NR                |
| 9     | DMAP       | No       | NR                |
| 10    | No         | No       | NR                |
| 11    | t-BuOK     | CoCl₂    | 51                |
| 12    | t-BuOK     | Cu(OAc)₂·H₂O | 0             |
| 13    | t-BuOK     | CuBr     | 0                 |
| 14    | t-BuOK     | Zn(OAc)₂ | 0                 |

<sup>a</sup>Reaction conditions: 1a (0.3 mmol), 2a (0.45 mmol), Catalyst (10 mol %), Base (1.5 equiv), DMF (2.0 mL), 6 h, at room temperature. <sup>b</sup>Isolated yield. N.R. = no reaction.

**Table S2.** Optimization of solvents<sup>a</sup>

![Chemical structure](image)

| Entry | Solvent | Yield<sup>b</sup> |
|-------|---------|-------------------|
| 1     | DMF     | 53                |
| 2     | DMAC    | 41                |
| 4     | EtOH    | NR                |
| 5     | HFIP    | NR                |
| 6     | Dioxane | NR                |
| 7     | DCE     | NR                |
| 8     | CH₃CN   | NR                |
| 9     | Toluene | NR                |
| 10    | PhCF₃   | NR                |
| 11    | DMSO    | 35                |

<sup>a</sup>Reaction conditions: 1a (0.3 mmol), 2a (0.45 mmol), t-BuOK (1.5 equiv), Solvent (2.0 mL), 6 h, at room temperature. <sup>b</sup>Isolated yield. DMF = N,N-Dimethylformamide; DMAC = N,N-Dimethylacetamide; HFIP = 1,1,1,3,3,3-Hexafluoroisopropanol; DMSO = Dimethyl sulfoxide; N.R. = no reaction.
Table S3. Optimization of dosages

![Chemical structure](image)

| Entry | 2a (equiv) | t-BuOK (equiv) | t (h) | Yield (%) |
|-------|------------|----------------|-------|-----------|
| 1     | 1.5        | 1.5            | 6     | 53        |
| 2     | 1.5        | 1.0            | 6     | 41        |
| 3     | 1.5        | 2.0            | 6     | 71        |
| 4     | 1.5        | 2.5            | 6     | 69        |
| 5     | 1.0        | 2.0            | 6     | 51        |
| 6     | 2.0        | 2.0            | 6     | 78        |
| 7     | 2.5        | 2.0            | 6     | 76        |
| 8     | 2.0        | 2.0            | 2     | 86        |
| 9     | 2.0        | 2.0            | 4     | 80        |
| 10    | 2.0        | 2.0            | 12    | 63        |
| 11    | 2.0        | 2.0            | 2     | 75        |
| 12    | 2.0        | 2.0            | 2     | 83        |

*Reaction conditions: 1a (0.3 mmol), 2a (0.3-0.75 mmol), t-BuOK (1.0-2.5 equiv), DMF (1.0-3.0 mL), 2-12 h, at room temperature. *Isolated yield.

Table S4. Optimization of temperature

![Chemical structure](image)

| Entry | T (°C) | Yield (%) |
|-------|--------|-----------|
| 1     | 25     | 86        |
| 2     | 40     | 79        |
| 3     | 60     | 65        |

*Reaction conditions: 1a (0.3 mmol), 2a (0.6 mmol), t-BuOK (2 equiv), DMF (2.0 mL), 2 h, 25-60 °C. *Isolated yield.
5. Procedure for gram-scale reaction

To a solution of indolynaphthoquinone 1a (1.43 g), t-BuOK (1.12 g, 2.0 equiv) in DMF (33 mL) was added aniline 2a (0.93 g, 2.0 equiv). The reaction mixture was stirred at room temperature under air atmosphere for 2 h. After the completion of the reaction (monitored by TLC), the reaction was quenched with saturated salt water (120 ml) and the mixture was extracted with EtOAc (3 × 60 mL). The organic extracts were washed with brine, dried over Na₂SO₄, filtered and the solvent was removed in vacuo. The crude product was purified by silica gel column chromatography to give 3a in 83% yield.

To a solution of naphthoquinone 4a (0.79 g), t-BuOK (1.12 g, 2.0 equiv) in DMF (33 mL) was added aniline 2a (0.93 g, 2.0 equiv). The reaction mixture was stirred at room temperature under air atmosphere for 2 h. After the completion of the reaction (monitored by TLC), the reaction was quenched with saturated salt water (120 ml) and the mixture was extracted with EtOAc (3 × 60 mL). The organic extracts were washed with brine, dried over Na₂SO₄, filtered and the solvent was removed in vacuo. The crude product was purified by silica gel column chromatography to give 5a in 83% yield.
6. Characterization data of products

2-(1-methyl-1H-indol-3-yl)-3-(phenylamino)naphthalene-1,4-dione (3a)

Black solid, 86% yield; mp 218-220 °C. $^1$H NMR (400 MHz, DMSO-$d_6$) $\delta$ 8.73 (s, 1H), 8.07 (dd, $J = 16.0, 7.5$ Hz, 2H), 7.83 (dt, $J = 21.7, 7.4$ Hz, 2H), 7.25 (s, 1H), 7.21 (d, $J = 7.9$ Hz, 1H), 7.16 (d, $J = 8.1$ Hz, 1H), 6.98 (t, $J = 7.5$ Hz, 1H), 6.89 (t, $J = 7.4$ Hz, 1H), 6.72 – 6.46 (m, 5H), 3.63 (s, 3H).

$^{13}$C NMR (101 MHz, DMSO-$d_6$) $\delta$ 182.81, 182.31, 141.09, 138.79, 136.43, 134.84, 133.35, 133.21, 132.44, 131.16, 129.77, 126.71, 126.54, 126.33, 126.11, 122.25, 121.48, 121.13, 120.92, 119.32, 114.79, 109.61, 107.00, 32.76. HRMS calcd. For C$_{25}$H$_{19}$N$_2$O$_2^+$ (M+H)$^+$ 379.1447 found: 379.1441.

2-(1-methyl-1H-indol-3-yl)-3-(p-tolylamino)naphthalene-1,4-dione (3b)

Black solid, 88% yield; mp 225-227 °C. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.16 (ddd, $J = 14.2, 7.6, 1.0$ Hz, 2H), 7.73 (td, $J = 7.5, 1.4$ Hz, 1H), 7.69 – 7.58 (m, 2H), 7.31 (d, $J = 7.9$ Hz, 1H), 7.09 – 6.96 (m, 4H), 6.47 (d, $J = 8.2$ Hz, 2H), 6.40 (d, $J = 8.3$ Hz, 2H), 3.60 (s, 3H), 2.03 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ 184.36, 183.00, 140.43, 135.74, 134.95, 134.37, 132.73, 132.30, 131.22, 130.80, 127.78, 127.13, 126.64, 126.06, 121.60, 121.32, 120.89, 119.48, 113.03, 108.71, 32.62, 20.60. HRMS calcd. For C$_{26}$H$_{21}$N$_2$O$_2^+$ (M+H)$^+$ 393.1602 found: 393.1603.
2-((4-chlorophenyl)amino)-3-(1-methyl-1H-indol-3-yl)naphthalene-1,4-dione (3c)

Black solid, 69% yield; mp 221-223 °C. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.22 – 8.11 (m, 2H), 7.74 (dd, $J = 7.5$, 1.4 Hz, 1H), 7.68 (dd, $J = 7.4$, 1.3 Hz, 1H), 7.58 (s, 1H), 7.27 (d, $J = 6.7$ Hz, 2H), 7.08 (d, $J = 3.6$ Hz, 2H), 7.00 – 6.96 (m, 1H), 6.65 – 6.59 (m, 2H), 6.42 (d, $J = 8.7$ Hz, 2H), 3.68 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ 182.69, 182.38, 139.46, 139.41, 135.88, 134.46, 132.56, 131.39, 129.69, 126.74, 126.39, 126.31, 126.13, 126.10, 122.34, 122.07, 121.64, 121.61, 120.74, 119.63, 114.47, 109.05, 109.00, 106.73, 32.86. HRMS calcd. For C$_{25}$H$_{18}$ClN$_2$O$_2$ $^{(\text{M+H})}$ 413.1065 found: 413.1057.

2-((4-bromophenyl)amino)-3-(1-methyl-1H-indol-3-yl)naphthalene-1,4-dione (3d)

Black solid, 75% yield; mp 227-229 °C. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.17 (t, $J = 8.5$ Hz, 2H), 7.77 – 7.67 (m, 2H), 7.57 (s, 1H), 7.25 (dd, $J = 8.2$, 3.6 Hz, 2H), 7.11 – 7.06 (m, 2H), 7.00 – 6.95 (m, 1H), 6.76 (d, $J = 8.6$ Hz, 2H), 6.36 (d, $J = 8.7$ Hz, 2H), 3.69 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ 182.69, 182.39, 139.04, 136.32, 134.53, 134.46, 132.57, 131.48, 131.39, 129.33, 129.31, 126.74, 126.14, 122.72, 122.70, 121.66, 120.73, 119.77, 116.81, 116.39, 115.60, 115.11, 109.07, 106.37, 32.87. HRMS calcd. For C$_{25}$H$_{18}$BrN$_2$O$_2$ $^{(\text{M+H})}$ 457.0558 found: 457.0552.

2-((3-chlorophenyl)amino)-3-(1-methyl-1H-indol-3-yl)naphthalene-1,4-dione (3e)

Black solid, 73% yield; mp 211-213 °C. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.18 (dd, $J =
10.9, 7.6 Hz, 2H), 7.77 – 7.66 (m, 3H), 7.35 (s, 1H), 7.22 (d, J = 7.9 Hz, 1H), 7.03 (d, J = 3.6 Hz, 2H), 6.96 – 6.91 (m, 1H), 6.59 – 6.48 (m, 2H), 6.45 – 6.32 (m, 2H), 3.72 (s, 3H).

$^{13}$C NMR (101 MHz, CDCl$_3$) δ 183.07, 182.45, 138.51, 137.94, 135.99, 134.46, 132.63, 131.26, 127.25, 126.14, 122.47, 121.56, 120.62, 120.56, 119.69, 119.40, 114.66, 114.38, 108.88, 106.90, 106.62, 32.89.

HRMS calcd. For C$_{25}$H$_{18}$ClN$_2$O$_2$ $^{+}$ (M+H)$^+$ 413.1057 found: 413.1057.

2-(1-methyl-1H-indol-3-yl)-3-(o-tolylamino)naphthalene-1,4-dione (3f)

Black solid, 79% yield; mp 202–204 °C. $^1$H NMR (400 MHz, CDCl$_3$) δ 8.18 (ddd, J = 12.5, 7.7, 1.2 Hz, 2H), 7.75 (td, J = 7.5, 1.4 Hz, 1H), 7.68 (td, J = 7.5, 1.3 Hz, 1H), 7.46 (s, 1H), 7.29 (d, J = 7.8 Hz, 1H), 7.07 – 6.93 (m, 4H), 6.69 (d, J = 7.4 Hz, 1H), 6.56 (td, J = 7.4, 1.1 Hz, 1H), 6.44 (t, J = 7.1 Hz, 1H), 6.37 (d, J = 7.5 Hz, 1H), 3.61 (s, 3H), 2.18 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 182.94, 140.33, 136.24, 135.77, 134.44, 133.60, 132.37, 131.01, 130.77, 129.67, 128.91, 126.92, 126.69, 126.09, 123.88, 123.56, 121.73, 121.27, 120.39, 119.22, 113.30, 109.99, 108.75, 106.62, 32.69, 18.15. HRMS calcd. For C$_{26}$H$_{21}$N$_2$O$_3$ $^{+}$ (M+H)$^+$ 393.1604 found: 393.1603.

2-((2-methoxyphenyl)amino)-3-(1-methyl-1H-indol-3-yl)naphthalene-1,4-dione (3g)

Black solid, 72% yield; mp 210–212 °C. $^1$H NMR (400 MHz, CDCl$_3$) δ 8.27 – 8.06 (m, 2H), 7.79 – 7.64 (m, 3H), 7.27 (dd, J = 17.9, 8.9 Hz, 2H), 7.02 (d, J = 4.1 Hz, 2H), 6.94 – 6.86 (m, 1H), 6.55 (t, J = 7.5 Hz, 1H), 6.32 (dd, J = 12.2, 8.0 Hz, 2H), 6.19 (t, J = 7.6 Hz, 1H), 3.69 (s, 3H), 3.66 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 182.84, 139.40, 136.26, 134.26, 133.69, 132.29, 131.31, 130.90, 126.83, 126.60, 126.23, 126.01, 123.43, 121.11, 120.74, 120.61, 118.99, 117.85, 113.09, 109.98, 108.75, 108.58, 106.86, 55.17, 32.81. HRMS calcd. For C$_{26}$H$_{21}$N$_2$O$_3$ $^{+}$ (M+H)$^+$ 409.1551 found: 409.1552.

2-((2-chlorophenyl)amino)-3-(1-methyl-1H-indol-3-yl)naphthalene-1,4-dione (3h)
Black solid, 67% yield; mp 207-209 °C. \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 8.32 – 7.98 (m, 2H), 7.79 – 7.66 (m, 3H), 7.36 – 7.27 (m, 2H), 7.05 – 6.88 (m, 4H), 6.50 – 6.34 (m, 3H), 3.68 (s, 3H). \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) \(\delta\) 183.05, 182.52, 138.50, 138.39, 136.77, 135.83, 134.39, 132.64, 131.52, 127.77, 126.72, 126.16, 124.32, 123.31, 122.55, 121.52, 121.16, 120.76, 119.78, 114.49, 108.69, 106.07, 32.89. HRMS calcd. For C\(_{25}\)H\(_{18}\)ClN\(_2\)O\(_2\) (M+H\(^+\)) 413.1059 found: 413.1057.

**2-(1-methyl-1H-indol-3-yl)-3-(pyridin-2-ylamino)naphthalene-1,4-dione (3i)**

Black solid, 77% yield; mp 231-233 °C. \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 8.23 – 8.09 (m, 2H), 8.00 (s, 1H), 7.87 (d, \(J = 4.0\) Hz, 1H), 7.75 – 7.67 (m, 2H), 7.42 (s, 1H), 7.38 (d, \(J = 7.8\) Hz, 1H), 7.12 – 7.03 (m, 2H), 7.02 – 6.90 (m, 2H), 6.47 (dd, \(J = 6.8, 5.1\) Hz, 1H), 6.27 (d, \(J = 8.2\) Hz, 1H), 3.73 (s, 3H). \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) \(\delta\) 183.46, 182.30, 150.88, 146.81, 138.25, 136.42, 135.20, 133.17, 132.82, 132.01, 130.95, 126.71, 126.18, 125.77, 121.70, 121.21, 120.03, 117.15, 113.40, 108.98, 106.98, 33.00. HRMS calcd. For C\(_{24}\)H\(_{18}\)N\(_3\)O\(_2\) (M+H\(^+\)) 380.1394 found: 380.1399.

**2-(5-chloro-1-methyl-1H-indol-3-yl)-3-(phenylamino)naphthalene-1,4-dione (3j)**

Black solid, 68% yield; mp 225-227 °C. \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 8.24 (t, \(J = 7.6\) Hz, 2H), 7.83 – 7.72 (m, 3H), 7.34 (dd, \(J = 14.5, 0.9\) Hz, 1H), 7.20 (s, 1H), 7.04 (dd, \(J = 8.6, 1.3\) Hz, 1H), 6.97 (d, \(J = 8.6\) Hz, 1H), 6.76 (t, \(J = 7.6\) Hz, 2H), 6.68 (d, \(J = 7.1\) Hz, 1H), 6.60 (d, \(J = 7.8\) Hz, 2H), 3.66 (s, 3H). \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) \(\delta\) 182.81, 182.77, 139.87, 137.23, 134.66, 134.53, 133.43, 132.53, 132.50, 130.63, 127.64, 126.71, 126.58, 126.19, 125.29, 123.24, 121.54, 121.51, 121.49, 120.47, 112.69,
109.84, 106.69, 32.94. HRMS calcd. For C$_{25}$H$_{18}$ClN$_2$O$_2^+$ (M+H)$^+$ 413.1056 found: 413.1057.

### 2-(6-fluoro-1-methyl-1H-indol-3-yl)-3-(phenylamino)naphthalene-1,4-dione (3k)

![Chemical structure](image)

Black solid, 71% yield; mp 229-231 °C. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.29 – 8.06 (m, 2H), 7.76 (td, $J = 7.5, 1.3$ Hz, 1H), 7.71 – 7.64 (m, 2H), 7.26 – 7.22 (m, 1H), 7.05 (s, 1H), 6.78 – 6.62 (m, 5H), 6.51 (d, $J = 7.7$ Hz, 2H), 3.55 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ 182.90, 182.84, 160.89, 158.41, 140.08, 137.26, 136.28, 136.21, 134.52, 134.48, 132.49, 131.61, 130.64, 126.72, 126.67, 126.16, 123.24, 121.74, 121.64, 121.49, 108.25, 108.01, 95.38, 95.11, 32.80. HRMS calcd. For C$_{25}$H$_{18}$FN$_2$O$_2^+$ (M+H)$^+$ 397.1359 found: 397.1352.

### 2-(1,7-dimethyl-1H-indol-3-yl)-3-(phenylamino)naphthalene-1,4-dione (3l)

![Chemical structure](image)

Black solid, 62% yield; mp 223-225 °C. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.17 (dd, $J = 12.4, 7.6$ Hz, 2H), 7.78 – 7.71 (m, 1H), 7.70 – 7.60 (m, 2H), 7.10 (d, $J = 7.9$ Hz, 1H), 6.96 (s, 1H), 6.83 (t, $J = 7.5$ Hz, 1H), 6.68 (dt, $J = 22.4, 7.2$ Hz, 4H), 6.51 (d, $J = 7.5$ Hz, 2H), 3.87 (s, 3H), 2.58 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ 182.94, 182.86, 137.36, 135.01, 135.00, 134.36, 133.55, 132.77, 132.37, 130.81, 127.55, 126.67, 126.50, 126.07, 124.08, 122.90, 121.52, 120.65, 120.50, 119.76, 119.24, 118.95, 118.89, 109.98, 36.79, 19.56. HRMS calcd. For C$_{26}$H$_{21}$N$_2$O$_2^+$ (M+H)$^+$ 393.1609 found: 393.1603.

### 2-phenyl-3-(phenylamino)naphthalene-1,4-dione (3m)

![Chemical structure](image)

Black solid, 71% yield; mp 229-231 °C. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.29 – 8.06 (m, 2H), 7.76 (td, $J = 7.5, 1.3$ Hz, 1H), 7.71 – 7.64 (m, 2H), 7.26 – 7.22 (m, 1H), 7.05 (s, 1H), 6.78 – 6.62 (m, 5H), 6.51 (d, $J = 7.7$ Hz, 2H), 3.55 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ 182.90, 182.84, 160.89, 158.41, 140.08, 137.26, 136.28, 136.21, 134.52, 134.48, 132.49, 131.61, 130.64, 126.72, 126.67, 126.16, 123.24, 121.74, 121.64, 121.49, 108.25, 108.01, 95.38, 95.11, 32.80. HRMS calcd. For C$_{25}$H$_{18}$FN$_2$O$_2^+$ (M+H)$^+$ 397.1359 found: 397.1352.
Black solid, 61% yield; mp 161-163 °C. $^1$H NMR (400 MHz, CDCl$_3$) δ 8.08 (dd, $J$ = 11.2, 7.7 Hz, 2H), 7.68 (t, $J$ = 7.4 Hz, 2H), 7.60 (d, $J$ = 7.5 Hz, 1H), 7.16 (s, 1H), 6.91 (dd, $J$ = 9.2, 4.1 Hz, 4H), 6.79 (t, $J$ = 7.6 Hz, 2H), 6.72 (d, $J$ = 7.2 Hz, 1H), 6.51 (d, $J$ = 7.8 Hz, 2H). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 182.83, 182.48, 137.27, 134.86, 132.76, 132.39, 131.55, 130.45, 127.82, 127.45, 127.19, 127.10, 126.80, 126.50, 126.15, 125.90, 124.02, 123.82, 122.48, 121.74, 109.98. HRMS calcd. For C$_{22}$H$_{16}$NO$_2$+ (M+H)$^+$ 326.1185 found: 326.1181.

2-(phenylamino)naphthalene-1,4-dione (5a)$^3$

Red solid, 91% yield; mp 182-184 °C. $^1$H NMR (400 MHz, DMSO-d$_6$) δ 9.21 (s, 1H), 8.03 (d, $J$ = 7.5 Hz, 1H), 7.92 (d, $J$ = 7.5 Hz, 1H), 7.83 (t, $J$ = 7.0 Hz, 1H), 7.75 (t, $J$ = 7.0 Hz, 1H), 7.45 – 7.35 (m, 4H), 7.20 (t, $J$ = 7.2 Hz, 1H), 6.08 (s, 1H). $^{13}$C NMR (101 MHz, DMSO-d$_6$) δ 183.01, 181.99, 146.61, 138.48, 135.32, 133.06, 132.99, 130.84, 129.73, 126.55, 125.70, 124.13, 102.35.

2-(p-tolylamino)naphthalene-1,4-dione (5b)$^4$

Red solid, 89% yield; mp 197-199 °C. $^1$H NMR (400 MHz, CDCl$_3$) δ 8.07 – 8.02 (m, 2H), 7.69 (t, $J$ = 7.5 Hz, 1H), 7.61 (d, $J$ = 7.7 Hz, 1H), 7.16 (d, $J$ = 8.2 Hz, 3H), 7.10 (d, $J$ = 8.2 Hz, 2H), 6.29 (s, 1H), 2.30 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 182.10, 181.44, 144.90, 135.46, 135.17, 134.87, 132.24, 130.22, 128.72, 126.47, 125.81, 123.85, 122.71, 122.52, 103.01, 20.98.

2-((4-(methylthio)phenyl)amino)naphthalene-1,4-dione (5c)$^5$

Red solid, 83% yield; mp 166-168 °C. $^1$H NMR (400 MHz, CDCl$_3$) δ 7.95 (d, $J$ = 7.7 Hz, 2H), 7.60 (t, $J$ = 7.6 Hz, 1H), 7.51 (t, $J$ = 7.5 Hz, 1H), 7.40 (s, 1H), 7.14 (t, $J$ = 6.8 Hz, 2H), 7.07 (dd, $J$ = 7.5, 4.0 Hz, 2H), 7.02 (d, $J$ = 7.5 Hz, 1H), 6.98 (d, $J$ = 7.7 Hz, 1H), 6.80 (s, 1H), 2.40 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 181.87, 152.94, 137.99, 134.64, 134.43, 132.57, 131.80, 129.29, 127.96, 126.77, 124.45, 124.14, 102.96, 21.63.
Hz, 2H), 7.05 (d, J = 8.5 Hz, 2H), 6.20 (s, 1H), 2.35 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 183.75, 181.95, 144.62, 135.79, 134.90, 134.61, 134.27, 133.19, 132.31, 130.30, 127.85, 126.49, 126.14, 125.95, 123.09, 103.34, 16.16.

2-((3-methoxyphenyl)amino)naphthalene-1,4-dione (5d)$^6$

Red solid, 76% yield; mp 163-165 °C. $^1$H NMR (400 MHz, CDCl$_3$) δ 8.11 (ddd, J = 7.5, 4.2, 1.1 Hz, 2H), 7.75 (dt, J = 7.6, 3.7 Hz, 1H), 7.67 (dt, J = 7.5, 3.7 Hz, 1H), 7.55 (s, 1H), 7.31 (t, J = 8.1 Hz, 1H), 6.87 (dd, J = 7.9, 1.8 Hz, 1H), 6.80 (t, J = 2.2 Hz, 1H), 6.75 (dd, J = 8.3, 2.3 Hz, 1H), 6.45 (s, 1H), 3.82 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 183.92, 182.01, 160.60, 144.55, 138.59, 134.90, 133.17, 132.34, 130.44, 130.32, 126.52, 126.15, 114.75, 110.97, 108.46, 103.80, 55.43.

2-((3-chlorophenyl)amino)naphthalene-1,4-dione (5e)$^4$

Red solid, 72% yield; mp 151-153 °C. $^1$H NMR (400 MHz, DMSO-$d_6$) δ 9.25 (s, 1H), 8.04 (d, J = 7.4 Hz, 1H), 7.94 (d, J = 7.4 Hz, 1H), 7.82 (t, J = 7.3 Hz, 1H), 7.75 (t, J = 7.3 Hz, 1H), 7.45 – 7.33 (m, 3H), 7.21 (d, J = 7.8 Hz, 1H), 6.16 (s, 1H). $^{13}$C NMR (101 MHz, DMSO-$d_6$) δ 183.29, 181.54, 145.93, 140.26, 135.22, 133.07, 131.16, 130.29, 126.54, 125.73, 125.14, 124.58, 123.53, 122.14, 103.56.

2-(o-tolylamino)naphthalene-1,4-dione (5f)$^7$

Red solid, 77% yield; mp 141-143 °C. $^1$H NMR (400 MHz, DMSO-$d_6$) δ 8.98 (s, 1H), 8.00 (dd, J = 7.6, 0.9 Hz, 1H), 7.88 (dd, J = 7.6, 0.9 Hz, 1H), 7.79 (td, J = 7.5, 1.3 Hz, 1H), 7.71 (td, J = 7.5, 1.3 Hz, 1H), 7.36 – 7.19 (m, 4H), 5.31 (s, 1H), 2.18 (s, 3H). $^{13}$C NMR (101 MHz, DMSO-$d_6$) δ 182.47, 181.84, 148.13, 136.55, 135.23, 134.96,
133.20, 132.84, 131.46, 130.85, 127.58, 127.31, 127.18, 126.40, 125.72, 101.72, 17.85.

2-((2-hydroxyphenyl)amino)naphthalene-1,4-dione (5g)

Red solid, 62% yield; mp 193-195 °C. \(^1\)H NMR (400 MHz, DMSO-
\(d_6\)) \(\delta\) 9.31 (s, 1H), 8.02 (d, \(J = 7.4 \text{ Hz, 1H}\)), 7.90 (dd, \(J = 11.6, 8.8 \text{ Hz, 3H}\)), 7.82 (t, \(J = 7.2 \text{ Hz, 1H}\)), 7.75 (t, \(J = 7.3 \text{ Hz, 1H}\)), 7.43 (d, \(J = 8.4 \text{ Hz, 2H}\)), 7.32 (s, 1H), 6.23 (s, 1H). \(^{13}\)C NMR (101 MHz, DMSO-
\(d_6\)) \(\delta\) 183.29, 181.86, 167.65, 145.80, 141.40, 135.35, 133.22, 132.85, 132.63, 130.83, 130.68, 129.12, 126.63, 125.74, 122.75, 109.98.

2-((2-chlorophenyl)amino)naphthalene-1,4-dione (5h)

Red solid, 65% yield; mp 143-145 °C. \(^1\)H NMR (400 MHz, DMSO-
\(d_6\)) \(\delta\) 9.03 (s, 1H), 8.02 (d, \(J = 7.5 \text{ Hz, 1H}\)), 7.90 (d, \(J = 7.5 \text{ Hz, 1H}\)), 7.82 (td, \(J = 7.5, 1.2 \text{ Hz, 1H}\)), 7.75 (td, \(J = 7.5, 1.2 \text{ Hz, 1H}\)), 7.60 (d, \(J = 7.9 \text{ Hz, 1H}\)), 7.51 – 7.38 (m, 2H), 7.38 – 7.29 (m, 1H), 5.46 (s, 1H). \(^{13}\)C NMR (101 MHz, DMSO-
\(d_6\)) \(\delta\) 182.81, 181.57, 146.91, 135.41, 135.24, 133.18, 132.90, 130.72, 130.68, 130.12, 128.81, 128.72, 128.32, 126.54, 125.83, 103.41.

2-(naphthalen-1-ylamino)naphthalene-1,4-dione (5i)

Red solid, 83% yield; mp 157-159 °C. \(^1\)H NMR (400 MHz, DMSO-
\(d_6\)) \(\delta\) 9.50 (s, 1H), 8.08 (dd, \(J = 7.5, 1.1 \text{ Hz, 1H}\)), 8.03 – 7.98 (m, 1H), 7.94 (d, \(J = 8.2 \text{ Hz, 1H}\)), 7.91 – 7.86 (m, 2H), 7.79 (dtd, \(J = 21.3, 7.4, 1.4 \text{ Hz, 2H}\)), 7.61 – 7.48 (m, 4H), 5.22 (s, 1H). \(^{13}\)C NMR (101 MHz, DMSO-
\(d_6\)) \(\delta\) 182.57, 181.79, 149.31, 135.21, 134.47, 134.33, 133.17, 132.96, 131.02, 129.35, 128.84, 127.95, 127.06, 127.00, 126.49, 126.37, 125.73, 125.03, 123.63, 102.60.
2-((3,5-di-tert-butylphenyl)amino)naphthalene-1,4-dione (5j)

Red solid, 78% yield; mp 142-144 °C. $^1$H NMR (400 MHz, CDCl$_3$) δ 8.11 (d, $J = 7.8$ Hz, 2H), 7.74 (td, $J = 7.6$, 1.1 Hz, 1H), 7.68 – 7.58 (m, 2H), 7.28 (d, $J = 1.5$ Hz, 1H), 7.10 (d, $J = 1.5$ Hz, 2H), 6.33 (s, 1H), 1.34 (s, 19H). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 183.77, 182.23, 152.57, 145.21, 136.73, 134.83, 133.37, 132.17, 130.37, 126.44, 126.13, 120.04, 117.28, 103.01, 35.02, 31.37. HRMS calcd. For C$_{22}$H$_{16}$NO$_2$ (M+H)$^+$ 362.2117 found: 362.2120.

2-(pyridin-2-ylamino)naphthalene-1,4-dione (5k)$^{10}$

Red solid, 71% yield; mp 201-203 °C. $^1$H NMR (400 MHz, DMSO-$d_6$) δ 9.45 (s, 1H), 8.38 (dd, $J = 4.8$, 1.2 Hz, 1H), 8.04 (dd, $J = 7.6$, 6.8 Hz, 2H), 7.94 (d, $J = 7.4$ Hz, 1H), 7.84 (td, $J = 7.4$, 1.1 Hz, 1H), 7.80 – 7.72 (m, 2H), 7.55 (d, $J = 8.3$ Hz, 1H), 7.03 (dd, $J = 6.7$, 5.2 Hz, 1H). $^{13}$C NMR (101 MHz, DMSO-$d_6$) δ 184.73, 181.84, 154.22, 147.73, 143.13, 138.30, 135.23, 133.40, 132.46, 130.80, 126.70, 125.69, 118.47, 115.68, 110.51.

2-(propylamino)naphthalene-1,4-dione (5l)

Yellow solid, 72% yield; mp 165-167 °C. $^1$H NMR (400 MHz, DMSO-$d_6$) δ 7.93 (dd, $J = 15.0$, 7.6 Hz, 2H), 7.80 (dd, $J = 10.7$, 4.3 Hz, 1H), 7.72 – 7.65 (m, 1H), 7.54 (t, $J = 5.8$ Hz, 1H), 5.64 (s, 1H), 3.11 (dd, $J = 13.9$, 6.6 Hz, 2H), 1.57 (dd, $J = 14.5$, 7.3 Hz, 2H), 0.88 (t, $J = 7.4$ Hz, 3H). $^{13}$C NMR (101 MHz, DMSO-$d_6$) δ 181.72, 181.63, 148.99, 135.24, 132.52, 132.25, 130.35, 126.30, 125.73, 99.62, 43.97, 21.14, 11.84. HRMS calcd. For C$_{22}$H$_{16}$NO$_2$ (M+H)$^+$ 216.1019 found: 216.1025.

5-methyl-6-phenyl-5,6-dihydrobenzo[f]indolo[2,3-b]indole-7,12-dione (6a)
Red solid, 81 % yield; mp 275-277 °C. $^1$H NMR (400 MHz, CDCl$_3$) δ 8.35 (d, $J = 7.3$ Hz, 1H), 8.14 (d, $J = 5.9$ Hz, 1H), 7.94 (d, $J = 5.5$ Hz, 1H), 7.60 (d, $J = 15.9$ Hz, 7H), 7.36 – 7.23 (m, 3H), 7.17 (d, $J = 7.6$ Hz, 1H), 3.24 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 181.88, 174.08, 143.50, 136.44, 134.64, 133.08, 132.28, 129.81, 129.49, 127.94, 125.99, 124.18, 122.63, 121.09, 119.90, 109.28, 30.09. HRMS calcd. For C$_{25}$H$_{16}$N$_2$O$_2$Na$^+$ (M+Na)$^+$ 399.1104 found 399.1101.

2-chloro-5-methyl-6-phenyl-5,6-dihydrobenzo[f]indolo[2,3-b]indole-7,12-dione (6b)

Red solid, 62 % yield; mp 261-263 °C. $^1$H NMR (400 MHz, CDCl$_3$) δ 8.29 – 8.28 (m, 1H), 8.14 – 8.12 (m, 1H), 7.92 (dd, $J = 6.3$, 1.2 Hz, 1H), 7.63 – 7.56 (m, 7H), 7.22 (d, $J = 2.2$ Hz, 1H), 7.08 (s, 1H), 3.25 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 181.53, 174.30, 141.68, 136.21, 134.43, 133.12, 132.98, 132.47, 129.91, 129.52, 127.93, 126.55, 126.06, 126.03, 123.98, 122.02, 120.92, 110.18, 77.29, 76.97, 76.65, 30.23. HRMS calcd. For C$_{25}$H$_{15}$ClN$_2$O$_2$Na$^+$ (M+Na)$^+$ 433.0714 found: 433.0719.

3-fluoro-5-methyl-6-phenyl-5,6-dihydrobenzo[f]indolo[2,3-b]indole-7,12-dione (6c)

Red solid, 56 % yield; mp 281-283 °C. $^1$H NMR (400 MHz, CDCl$_3$) δ 8.28 (dd, $J = 8.6$, 5.6 Hz, 1H), 8.17 – 8.14 (m, 1H), 7.99 – 7.94 (m, 1H), 7.63 – 7.57 (m, 7H), 7.03
– 6.98 (m, 1H), 6.90 (dd, J = 9.6, 2.2 Hz, 1H), 3.23 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ 181.81, 174.18, 136.27, 134.64, 133.13, 133.08, 132.35, 129.89, 129.52, 127.88, 126.07, 126.01, 123.56, 123.46, 109.08, 108.85, 97.03, 96.75, 77.29, 77.17, 76.97, 76.65, 30.31. HRMS calcd. For C$_{25}$H$_{16}$FN$_2$O$_2$ $^{+}$ (M+H)$^+$ 395.1190 found: 395.1195.
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8. Copies of ¹H, ¹³C and ¹⁹F NMR spectra for all Compounds
2-(1-methyl-1H-indol-3-yl)-3-(phenylamino)naphthalene-1,4-dione (3a)
2-(1-methyl-1H-indol-3-yl)-3-(p-tolylamino)naphthalene-1,4-dione (3b)
2-((4-chlorophenyl)amino)-3-(1-methyl-1H-indol-3-yl)naphthalene-1,4-dione (3c)
2-((4-bromophenyl)amino)-3-(1-methyl-1H-indol-3-yl)naphthalene-1,4-dione (3d)
2-((3-chlorophenyl)amino)-3-(1-methyl-1H-indol-3-yl)naphthalene-1,4-dione (3e)
2-(1-methyl-1H-indol-3-yl)-3-(o-tolylamino)naphthalene-1,4-dione (3f)
2-((2-methoxyphenyl)amino)-3-(1-methyl-1H-indol-3-yl)naphthalene-1,4-dione (3g)
2-((2-chlorophenyl)amino)-3-(1-methyl-1H-indol-3-yl)naphthalene-1,4-dione (3h)
2-(1-methyl-1H-indol-3-yl)-3-(pyridin-2-ylamino)naphthalene-1,4-dione (3i)
2-(5-chloro-1-methyl-1H-indol-3-yl)-3-(phenylamino)naphthalene-1,4-dione (3j)
2-(6-fluoro-1-methyl-1H-indol-3-yl)-3-(phenylamino)naphthalene-1,4-dione (3k)
2-(1,7-dimethyl-1H-indol-3-yl)-3-(phenylamino)naphthalene-1,4-dione (3l)
2-phenyl-3-(phenylamino)naphthalene-1,4-dione (3m)
2-(phenylamino)naphthalene-1,4-dione (5a)
2-(p-tolylamino)naphthalene-1,4-dione (5b)
2-((4-(methylthio)phenyl)amino)naphthalene-1,4-dione (5c)
2-((3-methoxyphenyl)amino)naphthalene-1,4-dione (5d)
2-((3-chlorophenyl)amino)naphthalene-1,4-dione (5e)
2-(o-tolylamino)naphthalene-1,4-dione (5f)
2-((2-hydroxyphenyl)amino)naphthalene-1,4-dione (5g)
2-((2-chlorophenyl)amino)napthalene-1,4-dione (5h)
2-(naphthalen-1-ylamino)naphthalene-1,4-dione (5i)
2-((3,5-di-tert-butylphenyl)amino)naphthalene-1,4-dione (5j)
2-(pyridin-2-ylamino)naphthalene-1,4-dione (5k)
2-(propy lamino)naphthalene-1,4-dione (5l)
5-methyl-6-phenyl-5,6-dihydrobenzo[f]indolo[2,3-b]indole-7,12-dione (6a)
2-chloro-5-methyl-6-phenyl-5,6-dihydrobenzo[f]indolo[2,3-b]indole-7,12-dione (6b)
3-fluoro-5-methyl-6-phenyl-5,6-dihydrobenzo[\textit{f}]indolo[2,3-\textit{b}]indole-7,12-dione (6c)
