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Diversity-Oriented Synthesis of Ketoindoloquinoxalines and Indolotriazoloquinoxalines from 1-(2-Nitroaryl)-2-alkynylindoles

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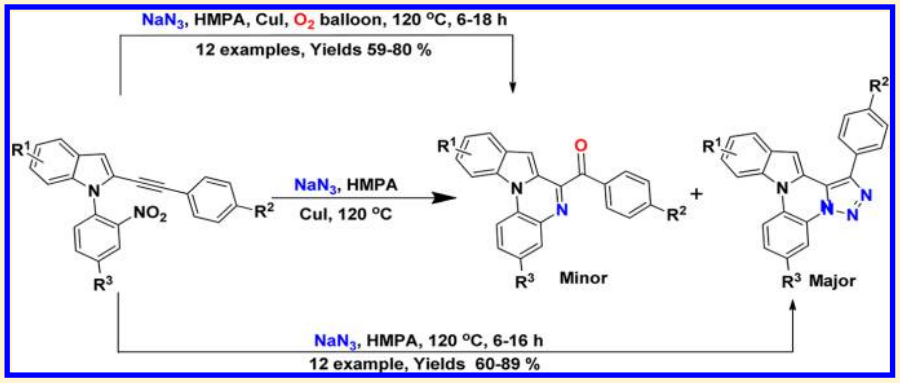
Supporting Information



ABSTRACT: A one-pot protocol for the diversity-oriented synthesis of two indole-based annulated polyheterocycles, ketoindoloquinoxalines and indolotriazoloquinoxalines, has been described. The salient features of the methodology involves either a metal/O_2-catalyzed aminooxygenation or a [3 + 2] cycloaddition pathway.

INTRODUCTION

The activated indole ring, owing to the presence of N1, C-2, and C-3 as three nucleophilic centers, serves as a "versatile scaffold" for the diversity-oriented synthesis[1] of structurally diverse indole-based annulated polyheterocycles. The indole-derived polyheterocycles are widely present in many natural products[2] and are associated with pharmacological activities[3] ranging from anticancer[4] to antibacterial[5] and antiviral activities.[6] In view of the therapeutic significance of these species, developing one-pot syntheses[7] via cascade[8]/domino reactions[9] has always remained an attractive task for chemists. In recent years, electrophilic alkynes have been widely employed as reactants in a one-pot reaction for the construction of annulated polyheterocycles.[10] This could be attributed to their ability to undergo annulation via an intramolecular nucleophilic attack in the presence/absence of transition metals.

Following this clue, we reported several new routes for the one-pot synthesis of indole-based natural products as well as polyheterocycles[11] by employing indole derivatives and terminal/internal alkynes as reactants. Recently, we covalently linked both the indole and alkyne into a single entity and the resulting 2-alkynylindoles[12] (comprising both nucleophilic and electrophilic centers) were exploited as substrates for the synthesis of structurally diverse heterocycles either in a one-pot format or in two steps.

In continuation of this, we next embarked on a search for a one-pot synthesis of ketoindoloquinoxalines from N1-susbtituted 2-alkynylindoles. The motivation stemmed from following our exploratory experiments toward the synthesis of indolotriazoloquinoxaline from the 2-alkynylindole derivative. We made an unprecedented observation of an oxygen insertion reaction affording a ketoindoloquinoxaline in a trace amount. Indoloquinoxalines are bioactive compounds, and in particular, indolo[1,2-*a*]quinoxalines exhibit antifungal activities[13] in vitro against phytopathogenic fungi. A careful survey of the literature failed to report any synthesis for ketoindolo[1,2-*a*]quinoxalines following incorporation of an oxygen as a keto group. The reported strategies for indolo[1,2-*a*]quinoxalines involved the usage of 1-(2-aminophenyl)indoles as a common substrate with either alkenes[14] or alkynes[15] as the second reactant (Figure 1).

Herein, we report the diversity-oriented synthesis of two indole-based annulated polyheterocycles, ketoindoloquinoxalines **2** and indolotriazoloquinoxalines **3**, from the common intermediates 1-(2-nitroaryl)-2-alkynylindoles **1**.

RESULTS AND DISCUSSION

In our effort directed toward azide−alkyne dipolar cycloaddition[16] involving 6-((4-(*tert*-butyl)phenyl)ethynyl)-5-(2-nitrophenyl)-5*H*-[1,3]dioxolo[4,5-*f*]indole (**1a**) and NaN_3, we

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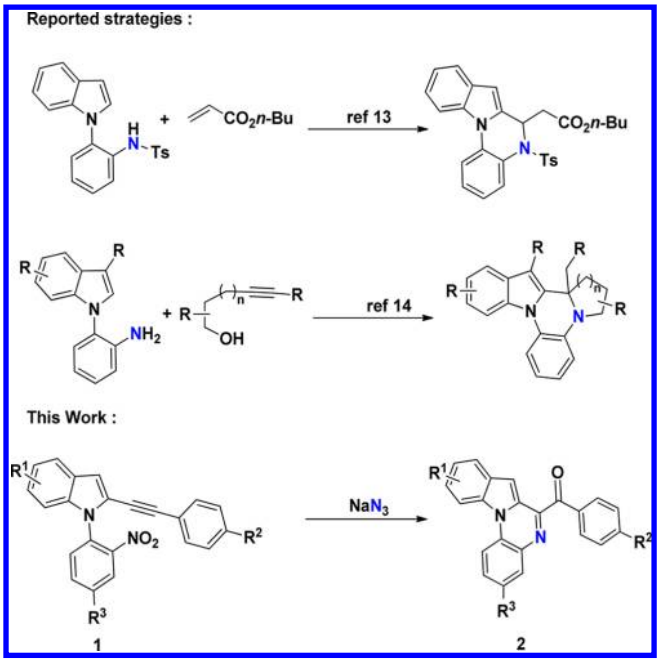
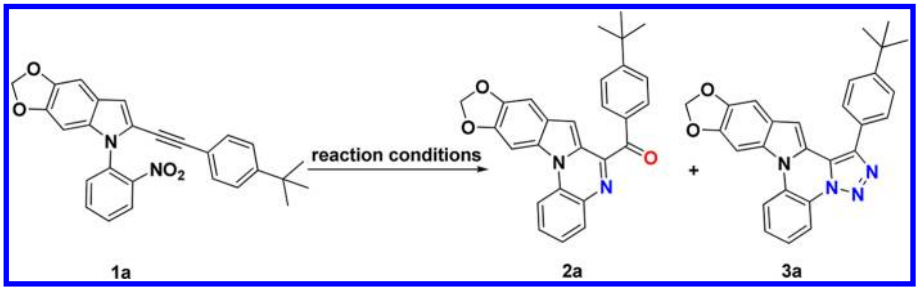


Figure 1. Reported strategies and our work involving the synthesis of indolo[1,2-*a*]quinoxalines.

observed the formation of the minor side product **2a** in ∼5% isolated yield along with the major product indoloquinoxalinotriazole **3a** in 61% isolated yield (Table 1, entry 1). **2a** was characterized as [1,3]dioxolo[4′,5′:5,6]indolo[1,2-*a*]quinoxalin-6-yl(4-(*tert*-butyl)phenyl)methanone on the basis of spectral and X-ray analyses[17] (see the Supporting Information), pointing to the unprecedented incorporation of oxygen in the form of a keto group. The insertion of an oxygen atom[18] in the form of a keto group[19] remains a powerful tool for the synthesis of structurally diverse polyheterocycles. There are several reports in the literature on polyheterocycle-based natural products of therapeutic significance bearing a keto group appended to their framework.[20] Our findings thus demonstrate the ability of the substrate **1a** to afford the two distinct structurally diverse indole-based annulated polyheterocycles **2a** (tricyclic) and **3a** (tetracyclic) in a one-pot format.

Intrigued by these observations, we set out to study the course of cyclization that led to the formation of **2a** from **1a**, followed by the development of a method for the quantitative and selective synthesis of **2a** and **3a**. We envisaged that the products **2a** and **3a** could both originate from a single reactive intermediate (having azide and alkyne moieties in close proximity), with conversion preference for **3a** over that of **2a**. Initially, our studies commenced with the treatment of **1a** with sodium azide in the presence of CuI as a catalyst, air/water as a source of oxygen, and HMPA as a solvent. Though water as a source of oxygen failed to afford **2a** (Table 1, entry 5), the presence of air furnished **2a** in ∼5% isolated yield (Table 1, entry 4). Nevertheless, **3a** was formed under both conditions in 60% and 52% isolated yields, respectively. This prompted us to carry out the reaction in the presence of oxygen, and to our delight **2a** was obtained in 78% isolated yield (entry 6) as a major product along with the formation of **3a** in traces (<5% as evident by HPLC). Switching the solvent from HMPA to DMSO (entry 7) and DMF (entry 8) produced a mixture of **2a** and **3a**. Similarly, replacement of CuI with CuBr (entry 9) and

Table 1. Optimization of the Synthesis of Ketoindoloquinoxaline 2a and Indolotriazoloquinoxaline 3a[a]



entry	reaction conditions	temp (°C)	time (h)	yield[b] of **2a**/**3a** (%)
1	5 mol % CuI, HMPA	120	10	<5[c]/61
2	5 mol % CuI, DMSO	120	10	−/49
3	5 mol % CuI, toluene	120	24	NR
4	5 mol % CuI, HMPA, air	100	10	5/52
5	5 mol % CuI, HMPA, H_2O	120	10	-/60
6	**5 mol % CuI, HMPA, O_2**	**120**	**10**	**78/<5**[c]
7	5 mol % CuI, DMSO, O_2	120	24	53/15
8	5 mol % CuI, DMF, O_2	120	24	37/56
9	5 mol % CuBr, HMPA, O_2	120	24	42/49
10	5 mol % CuCl, HMPA, O_2	120	24	40/55
11	5 mol % AgI, HMPA, O_2	120	24	−/52
12	5 mol % $Pd(OAc)_2$, HMPA	120	24	NR
13	5 mol % $AuClPPh_3/AgSbF_6$, HMPA	120	24	NR
14	HMPA, O_2	120	12	21/57
15	**HMPA**	**120**	**7.5**	**−/73**
16	DMSO	120	10	−/45
17	ACN	80	24	NR

[a]NR = no reaction. All reactions were carried out with 5 equiv of NaN_3. [b]Isolated yields. [c]Yield based on HPLC.

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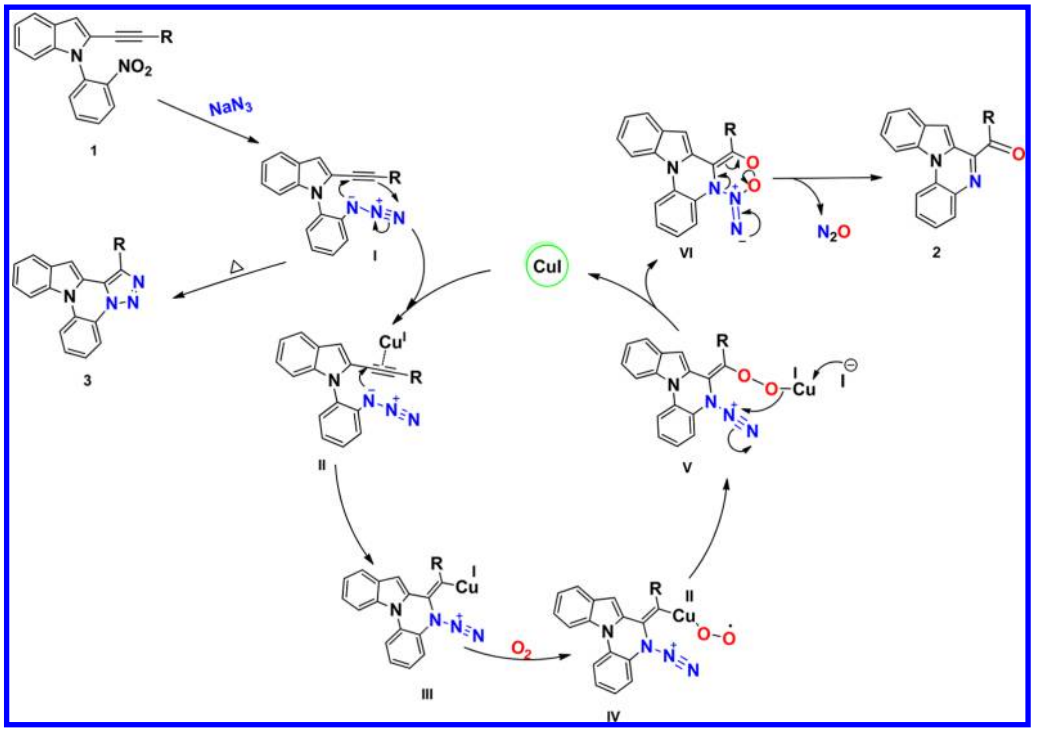

Figure 2. Plausible mechanism for the formation of **2** and **3**.

CuCl (entry 10) again resulted in poor selectivity, affording a mixture of **2a** and **3a** approximately in the ratio of 1:1. Surprisingly, the addition of AgI, in spite of the presence of oxygen, completely failed to afford **2a** and led to the selective formation of **3a**, albeit in 52% isolated yield (Table 1, entry 11). Other transition-metal catalysts such as Pd and Au−Ag failed to facilitate any transformation (entries 12 and 13), thereby suggesting the crucial role of CuI as a catalyst in the predominant transformation of **1a** to **2a**. This was further evident from the fact that carrying out the reaction in the presence of oxygen alone in HMPA without CuI produced a mixture of **2a** and **3a** in the approximate ratio of 1:3 (Table 1, entry 14). Interestingly, the absence of both CuI and oxygen in HMPA led to the selective formation of only **3a** in 73% isolated yield (Table 1, entry 15) in 7.5 h. Replacing HMPA with DMSO afforded **3a** in reduced yield (entry 16), whereas use of acetonitrile failed to produce any product (Table 1, entry 17). Our optimization studies thus led to the preferential formation of **2a** via insertion of oxygen in the presence of CuI and oxygen, whereas metal-free thermal conditions selectively afforded **3a** in satisfactory yields. To the best of our knowledge, this is the first report of diversity-oriented synthesis involving metal-catalyzed cascade annulation via aminooxygenation and metal-free annulation via [3 + 2] cycloadditions under thermal conditions from a single intermediate.

On the basis of earlier reports[21] and our own optimization studies, a plausible mechanism for the formations of **2** and **3** is depicted in Figure 2. The first step of the mechanism may involve aromatic nucleophilic substitution of the nitro group with sodium azide[22] to yield the intermediate **I**. Then, thermal conditions may directly afford the cyclic compound **3** via intramolecular [3 + 2] cycloaddition or the presence of a metal catalyst may generate the metal alkyne π complex **II** followed by an intramolecular nucleophilic attack by the nitrogen of the azide to yield the cyclic intermediate **III**. Next, the addition of oxygen to **III** may generate the organocopper peroxide intermediate **IV** followed by isomerization to the intermediate **V**. Then, the presence of iodide ion may regenerate the metal catalyst to afford intermediate **VI**, which may at that point undergo fragmentation to yield the final product **2** with the liberation of N_2O. While attempts to isolate the azide intermediate **I** were not fruitful, carrying out the reaction in the presence of TEMPO (free radical scavenger) afforded **3** as the only product by suppressing the formation of amino-oxygenation product **2**. These preliminary findings suggest that the reaction may be following a radical pathway where intermediate **IV** may be getting blocked by the addition of TEMPO.[23] Formation of **2** as a minor product in HMPA in the presence of oxygen alone (metal-free conditions; entry 14) may be attributed to the in situ generation of HMPA peroxide.[24] The latter species may be interacting[25] with the intermediate **I** to afford **2**; however, in the absence of any literature precedent involving hydroperoxide-mediated (non-metal-catalyzed) activation of alkynes, this needs detailed investigation.

Armed with the optimized reaction conditions leading to the selective synthesis of **2a** and **3a**, we next examined the substrate scope and limitation by introducing diversity in the three aromatic rings present in the substrate **1** as R^1, R^2, and R^3. Both electron-withdrawing and -donating substitutents have been introduced in the aromatic rings. R^1 in the aromatic ring of the indole has been substituted with 5-chloro, 5,6-dimethoxy, and 5,6-methylenedioxy groups, R^2 in the aromatic ring of the alkyne has been substituted with 4-*tert*-butyl and 4-methyl groups, and R^3 in the aromatic ring originating from the N of the indole has been substituted with 4-methyl, 4-trifluoromethyl, 4-fluoro, and 4-bromo groups. Accordingly, 12 compounds (**2a−l**) were synthesized in moderate to good yields (59−80%) (Scheme 1). The presence of electron-donating substituents on R^1 and R^3 furnished **2** in ≥70% isolated yields, whereas electron-withdrawing groups afforded **2** in reduced isolated yields ranging from 59 to 68%. Similarly, the presence of electron-donating groups in the aromatic ring of

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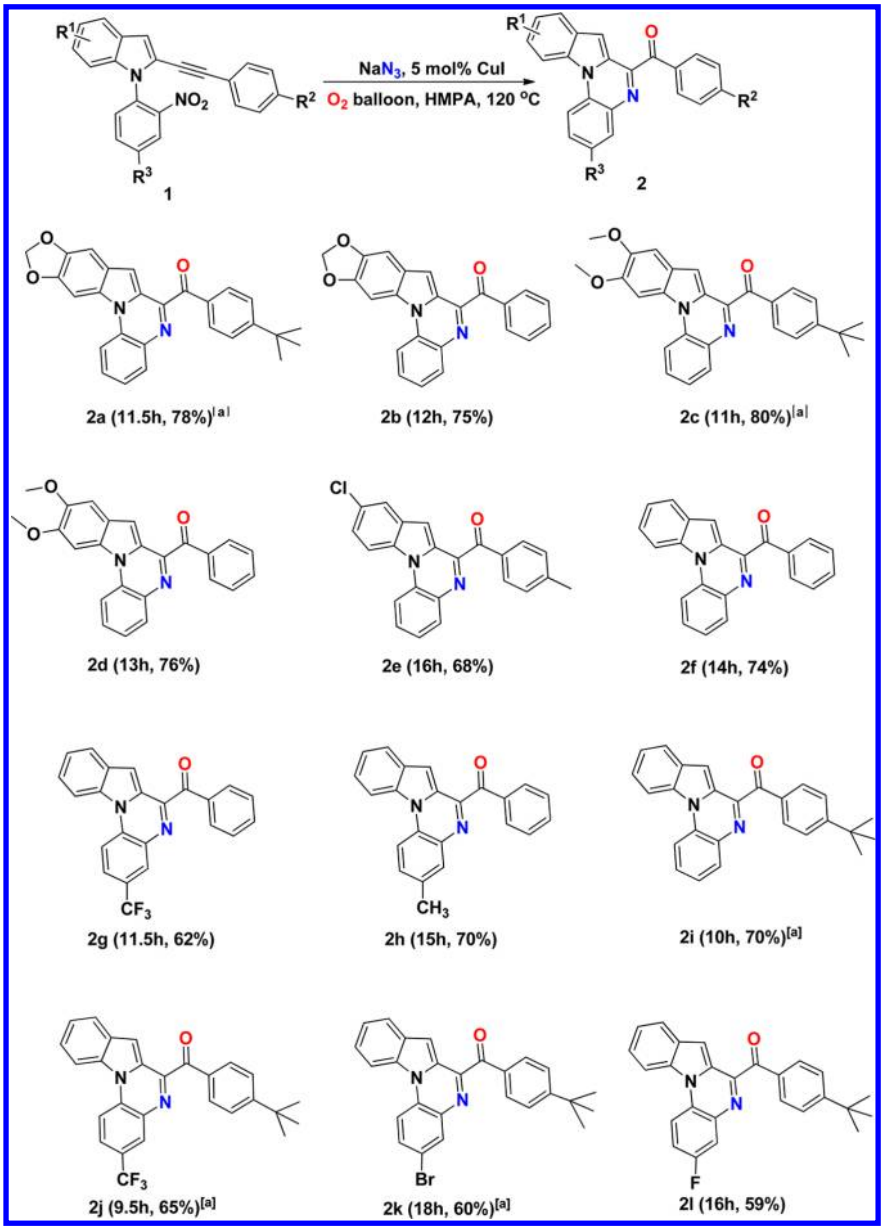
Scheme 1. Synthesis of 2a–l[a]



[a]Corresponding **3** was obtained in <5% yield based on HPLC.

the alkyne as R^2 afforded **2** in >70% isolated yield. However, replacing R^2 with an electron-withdrawing CN group or replacing the aromatic ring in the alkyne with an aliphatic group failed to produce the desired product. This may be attibuted to the weak activation of the internal alkyne toward nucleophilic attack. It is also noteworthy that products with R^2 as a *tert*-butyl group afforded the corresponding **3** via [3 + 2] cycloaddition in traces (<5% yield), as evidenced by HPLC. Next, we examined the substrate scope and limitation for the synthesis of indolotriazoloquinoxalines **3** using optimized reaction conditions involving heating of substrates **1** in HMPA under metal-free conditions. Altogether, 12 compounds **3a–l** with 3 points of diversity were synthesized in isolated yields ranging from 60 to 89% (Scheme 2). The nature of the substituent (R^1, R^2, R^3) had a significant effect on the cascade cyclization, which was evidenced by the isolated yields of final products. The substituents on substrate **1** with electron-donating groups such as 5,6-dimethoxy and 5,6-methylenedioxy groups as R^1 and 4-*tert*-butyl as R^2 afforded the final products in good yields. In contrast, introducing electron-withdrawing groups in R^1 such as 5-chloro and in R^3 such as 4-trifluoromethyl, 4-fluoro, and 4-bromo produced **3** in reduced yields.

CONCLUSION

In conclusion, we have demonstrated a diversity-oriented synthesis of two indole-based annulated polyheterocycles, ketoindoloquinoxalines and indolotriazoloquinoxalines, by treating 1-(2-nitroaryl)-2-alkynylindoles with NaN_3. The salient features involved either a preferential cascade cyclization via aminooxygenation with the elimination of nitrous oxide in the presence of CuI/oxygen or a thermally induced metal-free annulation via a [3 + 2] cycloaddition reaction.

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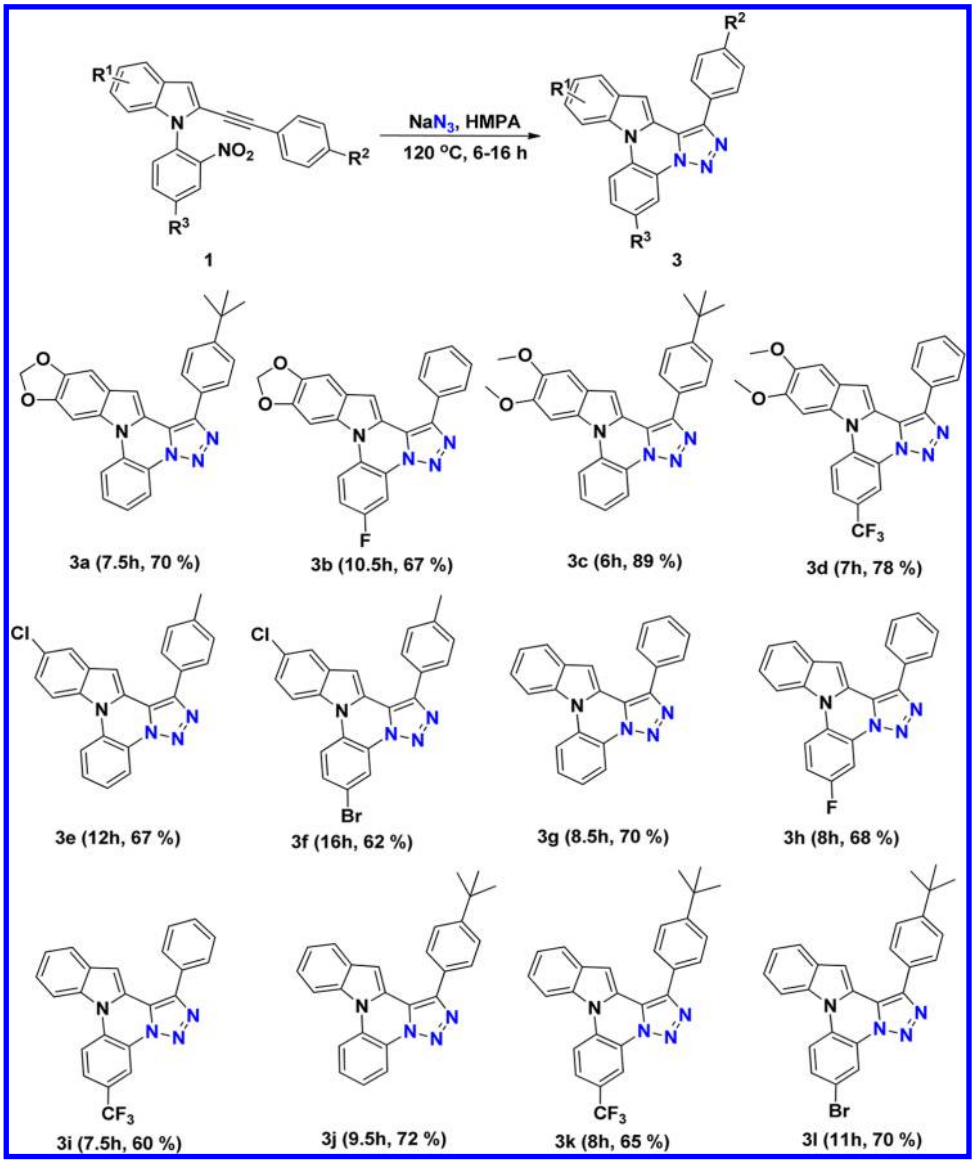
Scheme 2. Substrate Scope for Indolo Triazolo Quinoxalines 3



EXPERIMENTAL SECTION

General Information and Methods. All reagents and solvents were purchased from commercial sources and used without purification. NMR spectra were recorded with 400 MHz spectrometers for ^{1}H NMR and 100 MHz spectrometers for ^{13}C NMR. Chemical shifts δ are given in ppm relative to the residual signals of tetramethylsilane in $CDCl_3$ or deuterated solvent DMSO-d_6 for ^{1}H and ^{13}C NMR. Multiplicities are reported as follows: singlet (s), doublet (d), doublet of doublets (dd), doublet of triplets (dt), triplet (t), quartet (q), multiplet (m). High-resolution mass spectra were taken with a mass spectrometer. Column chromatography was performed using silica gel (100−200 mesh) as the stationary phase. All reactions were monitored by thin layer chromatography (TLC). The purity and characterization of these compounds were further established using HR/EI on Q-TOF, LC/MS Mass spectrometry. Melting points were measured on a capillary melting point apparatus and are uncorrected.

Typical Procedure for the Synthesis of Ketoindoloquinoxalines 2a−l. A 50 mL round-bottom flask equipped with a magnetic stir bar was charged with the 1-(2-nitroaryl)-2-alkynylindole (1 equiv) in 10 mL of HMPA, and to this clear solution was added sodium azide (5 equiv) and CuI (5 mol %) under an oxygen atmosphere at room temperature. The reaction mixture was transferred to an oil bath and stirred at 120 °C. After it was stirred vigorously for the appropriate time, the reaction mixture was removed from the oil bath, cooled to room temperature, filtered through a bed of Celite-R, diluted with water (50 mL), and extracted with ethyl acetate (3 × 30 mL). The resulting organic solution was washed with brine (25 mL), dried over anhydrous Na_2SO_4, filtered, and concentrated in vacuo. The resulting residue was purified by silica gel flash column chromatography with EtOAc/hexane as the eluent to afford **2**.

Typical Procedure for the Synthesis of Indolotriazoloquinoxalines 3a−l. A 50 mL round-bottom flask equipped with a magnetic stir bar was charged with the 1-(2-nitroaryl)-2-alkynylindole (1 equiv) in 10 mL of HMPA, and to this clear solution was added sodium azide (5 equiv) under a nitrogen atmosphere. The reaction mixture was transferred to an oil bath and stirred at 120 °C. After it was stirred vigorously for the appropriate time, the reaction mixture was removed from the oil bath, cooled to room temperature, filtered through a bed of Celite-R, diluted with water (50 mL), and extracted with ethyl acetate (3 × 30 mL). The resulting organic solution was washed with brine (25 mL), dried over anhydrous Na_2SO_4, filtered, and concentrated in vacuo. The resulting residue was purified by silica gel flash column chromatography with EtOAc/hexane as the eluent to afford **3**.

Typical Procedure for the Synthesis of 1-(2-Nitroaryl)-2-alkynylindoles 1a−p. A 50 mL round-bottom flask equipped with a

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magnetic stir bar was charged with the 2-alkynylindole (1 equiv) and 2-nitrofluorobenzene (1.1 equiv) in 20 mL of DMF; the reaction mixture was cooled to 0 °C, and to this solution was added sodium hydride (10 equiv) under a nitrogen atmosphere. The reaction mixture was stirred at room temperature. After it was stirred vigorously for the appropriate time, the reaction mixture was quenched with water and extracted with ethyl acetate (4 × 25 mL). The resulting organic solution was washed with brine (25 mL), dried over anhydrous Na_2SO_4, filtered, and concentrated in vacuo. The resulting residue was purified by silica gel flash column chromatography with EtOAc/hexane as the eluent to afford **1**.

Characterization of all Final and Intermediate Compounds. *([1,3]Dioxolo[4′,5′:5,6]indolo[1,2-a]quinoxalin-6-yl)(4-(tert-butyl)-phenyl)methanone (**2a**):* red solid; R_f = 0.60 (10/90 ethyl acetate/hexane); yield 78% (0.187 g); mp 186−188 °C; FT-IR (KBr) 3429, 3022, 2791, 2457, 1662, 1623, 1462, 1329 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.35 (d, J = 8.4 Hz, 1H), 8.12 (d, J = 8.4 Hz, 2H), 8.03 (d, J = 7.9 Hz, 1H), 7.89 (s, 1H), 7.66 (t, J = 8.2 Hz, 1H), 7.51 (d, J = 8.4 Hz, 2H), 7.45 (t, J = 8.0 Hz, 1H), 7.33 (s, 1H), 7.21 (s, 1H), 6.09 (s, 2H), 1.35 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 191.9, 157.8, 151.6, 147.8, 145.5, 135.2, 133.2, 131.4, 131.1, 130.6, 129.7, 128.1, 127.3, 125.6, 124.9, 124.3, 114.5, 102.8, 101.8, 100.0, 94.6, 35.4, 31.2 ppm; HRMS (ESI) calcd for $C_{27}H_{23}N_2O_3$ [M + H] 423.1708,, found 423.1703.

*([1,3]Dioxolo[4′,5′:5,6]indolo[1,2-a]quinoxalin-6-yl)(phenyl)-methanone (**2b**):* red solid; R_f = 0.62 (10/90 ethyl acetate/hexane); yield 75% (0.179 g); mp 145−147 °C; FT-IR (KBr) 3431, 3020, 2795, 1663, 1624, 1466, 1405, 1215 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.35 (d, J = 8.1 Hz, 1H), 8.17−8.15 (m, 2H), 8.03−8.01 (m, 1H), 7.89 (s, 1H), 7.68−7.61 (m, 2H), 7.52−7.42 (m, 3H), 7.36 (s, 1H), 7.22 (s, 1H), 6.10 (s, 2H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 192.4, 151.3, 148.0, 145.6, 136.0, 135.2, 133.9, 131.5, 131.3, 131.1, 129.9, 128.5, 127.3, 125.0, 124.4, 114.5, 102.8, 101.9, 100.1, 94.6 ppm; HRMS (ESI) calcd for $C_{23}H_{15}N_2O_3$ [M + H] 367.1082, found 367.1076.

*(4-(tert-Butyl)phenyl)(9,10-dimethoxyindolo[1,2-a]quinoxalin-6-yl)methanone (**2c**):* red solid; R_f = 0.58 (10/90 ethyl acetate/hexane); yield 80% (0.182 g); mp 112−114 °C; FT-IR (KBr) 3403, 3021, 2960, 1606, 1402, 1323, 1215 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.40 (d, J = 8.4 Hz, 1H), 8.13−8.11 (m, 2H), 8.06−8.03 (m, 1H), 7.85 (s, 1H), 7.70−7.66 (m, 1H), 7.52 (d, J = 8.5 Hz, 2H), 7.46−7.42 (m, 1H), 7.35 (s, 1H), 7.27 (s, 1H), 4.13 (s, 3H), 4.00 (s, 3H), 1.36 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 192.1, 157.9, 151.8, 149.4, 147.8, 135.3, 133.3, 131.4, 131.2, 130.9, 129.7, 127.7, 127.1, 125.7, 124.3, 123.8, 114.3, 102.5, 102.3, 96.9, 35.5, 31.3 ppm; HRMS (ESI) calcd for $C_{28}H_{27}N_2O_3$ [M + H] 439.2021, found 439.2021.

*(9,10-Dimethoxyindolo[1,2-a]quinoxalin-6-yl)(phenyl)-methanone (**2d**):* red solid; R_f = 0.52 (10/90 ethyl acetate/hexane); yield 76% (0.192 g); mp 170−172 °C; FT-IR (KBr) 3399, 3021, 2957, 2921, 2401, 1667, 1540, 1460, 1402 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.39 (d, J = 8.3 Hz, 1H), 8.18 (d, J = 7.4 Hz, 2H), 8.03 (d, J = 7.1 Hz, 1H), 7.84 (s, 1H), 7.70−7.62 (m, 2H), 7.51 (t, J = 7.7 Hz, 2H), 7.44 (t, J = 7.5 Hz, 1H), 7.38 (s, 1H), 7.28 (s, 1H), 4.13 (s, 3H), 4.00 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 192.5, 151.4, 149.4, 147.8, 135.9, 135.2, 133.8, 131.4, 131.1, 130.8, 129.8, 128.5, 127.7, 127.0, 124.2, 123.8, 114.2, 102.4, 102.2, 96.8, 56.6, 56.2 ppm; HRMS (ESI) calcd for $C_{24}H_{19}N_2O_3$ [M + H] 383.1395, found 383.1384.

*(9-Chloroindolo[1,2-a]quinoxalin-6-yl)(p-tolyl)methanone (**2e**):* red solid; R_f = 0.60 (10/90 ethyl acetate/hexane); yield 68% (0.134 g); mp 167−169 °C; FT-IR (KBr) 3401, 3019, 2958, 2925, 2400, 1606, 1384 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.48 (d, J = 8.3 Hz, 1H), 8.41 (d, J = 9.1 Hz, 1H), 8.09−8.07 (m, 3H), 7.93 (d, J = 1.9 Hz, 1H), 7.75−7.71 (m, 1H), 7.53−7.47 (m, 2H), 7.39 (s, 1H), 7.32 (d, J = 8.0 Hz, 2H), 2.46 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 191.6, 152.1, 145.2, 135.0, 133.1, 131.8, 131.3, 131.1, 130.8, 130.7, 129.4, 128.9, 128.6, 125.2, 124.9, 122.4, 115.7. 114.9, 101.8, 22.0 ppm; HRMS (ESI) calcd for $C_{23}H_{16}ClN_2O$ [M + H] 371.0951, found 371.0958.

*(Indolo[1,2-a]quinoxalin-6-yl)(phenyl)methanone (**2f**):* red solid; R_f = 0.68 (10/90 ethyl acetate/hexane); yield 74% (0.149 g); mp 155−157 °C; FT-IR (KBr) 3431, 2795, 1660, 1624, 1461, 1327, 1215, 1160 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.61 (d, J = 8.8 Hz, 1H), 8.45 (d, J = 8.6 Hz, 1H), 8.32 (s, 1H), 8.17 (d, J = 7.3 Hz, 2H), 8.00 (d, J = 8.0 Hz, 1H), 7.92 (d, J = 8.6 Hz, 1H), 7.68−7.62 (m, 2H), 7.55−7.49 (m, 5H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 191.6, 153.3, 135.5, 134.7, 134.2, 133.3, 133.0, 131.0, 129.8, 128.7, 127.4, 126.7, 125.7, 123.8, 123.7, 115.4, 114.4, 104.1 ppm; HRMS (ESI) calcd for $C_{22}H_{15}N_2O$ [M + H] 323.1184, found 323.1192.

*(Phenyl)(3-(trifluoromethyl)indolo[1,2-a]quinoxalin-6-yl)-methanone (**2g**):* red solid; R_f = 0.64 (10/90 ethyl acetate/hexane); yield 62% (0.132 g); mp 162−164 °C; FT-IR (KBr) 3432, 3020, 2795, 1662, 1624, 1466, 1405, 1326 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.62 (d, J = 8.7 Hz, 1H), 8.46 (d, J = 8.4 Hz, 1H), 8.33 (s, 1H), 8.19−8.17 (m, 2H), 8.01 (d, J = 8.0 Hz, 1H), 7.95−7.92 (m, 1H), 7.69−7.63 (m, 2H), 7.56−7.50 (m, 4H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 191.7, 153.4, 135.5, 134.8, 134.2, 133.4, 133.1, 131.1, 129.9, 128.7, 127.5, 126.8, 126.7, 126.4, 125.8, 125.2, 123.9, 123.8, 122.5, 115.4, 114.5, 104.1 ppm; HRMS (ESI) calcd for $C_{23}H_{14}F_3N_2O$ [M + H] 391.1058, found 391.1053.

*(3-Methylindolo[1,2-a]quinoxalin-6-yl)(phenyl)methanone (**2h**):* red solid; R_f = 0.62 (10/90 ethyl acetate/hexane); yield 70% (0.167 g); mp 179−181 °C; FT-IR (KBr) 3403, 3021, 2400, 1620, 1384, 1316, 1215 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.51 (d, J = 8.6 Hz, 1H), 8.37 (s, 1H), 8.19−8.17 (m, 2H), 7.99−7.93 (m, 2H), 7.66−7.57 (m, 2H), 7.53−7.45 (m, 4H), 7.29 (d, J = 8.1 Hz, 1H), 2.67 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 192.3, 150.9, 136.0, 133.8, 133.0, 132.8, 131.4, 131.1, 129.8, 128.5, 127.8, 125.6, 124.7, 123.3, 123.1, 115.3, 114.7, 114.2, 102.3, 22.6 ppm; HRMS (ESI) calcd for $C_{23}H_{17}N_2O$ [M + H] 337.1340, found 337.1335.

*(4-(tert-Butyl)phenyl)(indolo[1,2-a]quinoxalin-6-yl)methanone (**2i**):* red solid; R_f = 0.60 (10/90 ethyl acetate/hexane); yield 70% (0.168 g); mp 156−158 °C; FT-IR (KBr) 3429, 3022, 1661, 1625, 1461, 1402, 1216, 1158 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.57−8.55 (m, 1H), 8.50 (d, J = 8.7 Hz, 1H), 8.15−8.13 (m, 2H), 8.09−8.06 (m, 1H), 7.98 (d, J = 8.0 Hz, 1H), 7.74−7.69 (m, 1H), 7.61−7.57 (m, 1H), 7.55−7.52 (m, 2H), 7.49−7.45 (m, 3H), 1.37 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 191.6, 157.8, 152.3, 134.8, 132.9, 132.7, 131.4, 131.0, 130.9, 130.2, 129.5, 127.5, 125.5, 124.7, 124.3, 123.2, 122.9, 114.9, 114.5, 102.4, 35.3, 31.1 ppm; HRMS (ESI) calcd for $C_{26}H_{23}N_2O$ [M + H] 379.1810, found 379.1810.

*(3-Bromoindolo[1,2-a]quinoxalin-6-yl)(4-(tert-butyl)phenyl)-methanone (**2j**):* red solid; R_f = 0.64 (10/90 ethyl acetate/hexane); yield 65% (0.156 g); mp 120−122 °C; FT-IR (KBr) 3430, 3022, 1663, 1625, 1458, 1402, 1327, 1215 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.61 (d, J = 8.7 Hz, 1H), 8.45 (d, J = 8.6 Hz, 1H), 8.33 (s, 1H), 8.12 (d, J = 8.4 Hz, 2H), 7.99 (d, J = 8.0 Hz, 1H), 7.92 (d, J = 8.8 Hz, 1H), 7.66−7.62 (m, 1H), 7.55−7.49 (m, 4H), 1.36 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 191.2, 158.3, 153.7, 134.8, 133.1, 132.8, 131.1, 129.9, 128.8, 128.7, 127.6, 126.7, 126.6, 125.8, 125.7, 123.9, 123.8, 115.4, 114.5, 104.1, 35.5, 31.3 ppm; HRMS (ESI) calcd for $C_{27}H_{22}F_3N_2O$ [M + H] 447.1684, found 447.1696.

*(3-Bromoindolo[1,2-a]quinoxalin-6-yl)(4-(tert-butyl)phenyl)-methanone (**2k**):* red solid; R_f = 0.62 (10/90 ethyl acetate/hexane); yield 60% (0.144 g); mp 146−148 °C; FT-IR (KBr) 3434, 3020, 1663, 1625, 1538, 1465, 1405 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.40 (d, J = 8.8 Hz, 2H), 8.21 (d, J = 2.3 Hz, 1H), 8.10 (d, J = 8.5 Hz, 2H), 7.97 (d, J = 8.0 Hz, 1H), 7.79−7.77 (m, 1H), 7.62−7.58 (m, 1H), 7.53 (d, J = 8.5 Hz, 2H), 7.49−7.45 (m, 2H), 1.36 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 191.4, 158.2, 153.4, 136.3, 133.8, 132.9, 132.8, 131.1, 130.2, 129.7, 127.5, 125.8, 125.4, 123.7, 123.4, 116.7, 116.3, 114.5, 103.4, 35.5, 31.3 ppm; HRMS (ESI) calcd for $C_{26}H_{22}BrN_2O$ [M + H] 457.0915, found 457.0912.

*(4-(tert-Butyl)phenyl)(3-fluoroindolo[1,2-a]quinoxalin-6-yl)-methanone (**2l**):* red solid; R_f = 0.64 (10/90 ethyl acetate/hexane); yield 59% (0.123 g); mp 165−167 °C; FT-IR (KBr) 3400, 3023, 1625, 1541, 1503, 1386, 1266 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.57−8.42 (m, 2H), 8.14−8.06 (m, 2H), 7.98 (d, J = 8.0 Hz, 1H), 7.79−7.69 (m, 1H), 7.62−7.52 (m, 3H), 7.49−7.44 (m, 3H), 1.37 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 191.2, 158.3, 153.7, 134.7, 133.3, 133.0, 132.7, 131.0, 129.8, 128.7, 128.6, 127.5, 126.6, 125.8, 123.8,

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123.7, 115.3, 114.4, 104.0, 35.5, 31.2 ppm; HRMS (ESI) calcd for $C_{26}H_{22}FN_2O$ [M + H] 397.1716, found 397.1709.

1-(4-(tert-Butyl)phenyl)[1,3]dioxolo[4′,5′:5,6]indolo[1,2-a][1,2,3]-triazolo[5,1-c]quinoxaline (**3a**): gray fluffy solid; R_f = 0.58 (10/90 ethyl acetate/hexane); yield 70% (0.172 g); mp 185−187 °C; FT-IR (KBr) 3429, 1702, 1655, 1466, 1269 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.67 (d, J = 6.9 Hz, 1H), 8.29 (d, J = 8.2 Hz, 1H), 7.86 (d, J = 8.2 Hz, 2H), 7.73 (s, 1H), 7.62−7.56 (m, 3H), 7.44 (t, J = 7.9 Hz, 1H), 7.21 (s, 1H), 7.08 (s, 1H), 6.06 (s, 2H), 1.43 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 152.0, 146.8, 144.8, 141.9, 128.7, 128.3, 128.2, 128.1, 127.4, 125.9, 124.5, 124.4, 123.9, 123.5, 122.7, 117.8, 115.7, 101.7, 100.9, 99.8, 94.5, 35.0, 31.5 ppm; HRMS (ESI) calcd for $C_{27}H_{23}N_4O_2$ [M + H] 435.1821, found 435.1827.

6-Fluoro-1-phenyl[1,3]dioxolo[4′,5′:5,6]indolo[1,2-a][1,2,3]-triazolo[5,1-c]quinoxaline (**3b**): gray fluffy solid; R_f = 0.54 (10/90 ethyl acetate/hexane); yield 67% (0.165 g); mp 191−193 °C; FT-IR (KBr) 3400, 1627, 1462, 1386, 1215 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.94 (d, J = 1.5 Hz, 1H), 8.38 (d, J = 8.8 Hz, 1H), 7.91−7.89 (m, 2H), 7.84−7.82 (m, 1H), 7.69 (s, 1H), 7.60 (t, J = 7.1 Hz, 2H), 7.54−7.50 (m, 1H), 7.26 (s, 1H), 7.19 (s, 1H), 7.06 (s, 1H), 6.09 (s, 2H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 151.2, 147.9, 145.6, 135.9, 135.2, 133.8, 131.5, 131.3, 131.1, 130.6, 129.8, 128.5, 128.4, 128.2, 127.3, 125.0, 124.4, 114.5, 102.8, 101.9, 100.1, 94.6 ppm; HRMS (ESI) calcd for $C_{23}H_{14}FN_4O_2$ [M + H] 397.1100, found 397.1109.

1-(4-(tert-Butyl)phenyl)-11,12-dimethoxyindolo[1,2-a][1,2,3]-triazolo[5,1-c]quinoxaline (**3c**): gray fluffy solid; R_f = 0.48 (10/90 ethyl acetate/hexane); yield 89% (0.220 g); mp 178−180 °C; FT-IR (KBr) 3042, 1610, 1406, 1339, 1269 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.65 (d, J = 8.0 Hz, 1H), 8.31 (d, J = 8.4 Hz, 1H), 7.86 (d, J = 8.1 Hz, 2H), 7.68 (s, 1H), 7.60 (d, J = 8.1 Hz, 3H), 7.42 (t, J = 7.9 Hz, 1H), 7.22 (s, 1H), 7.15 (s, 1H), 4.06 (s, 3H), 3.95 (s, 3H), 1.43 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 151.9, 148.1, 146.9, 141.8, 128.3, 128.1, 127.5, 125.8, 124.1, 123.6, 123.4, 123.3, 122.7, 117.7, 115.2, 102.3, 100.4, 97.0, 56.6, 56.1, 35.0, 31.5 ppm; HRMS (ESI) calcd for $C_{28}H_{27}N_4O_2$ [M + H] 451.2134, found 451.2135.

11,12-Dimethoxy-1-phenyl-6-(trifluoromethyl)indolo[1,2-a]-[1,2,3]triazolo[5,1-c]quinoxaline (**3d**): gray fluffy solid; R_f = 0.52 (10/90 ethyl acetate/hexane); yield 78% (0.193 g); mp 192−194 °C; FT-IR (KBr) 3405, 1622, 1464, 1380, 1215 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.92 (s, 1H), 8.39 (d, J = 8.8 Hz, 1H), 7.90−7.84 (m, 3H), 7.63−7.49 (m, 4H), 7.19 (s, 1H), 7.12 (s, 1H), 4.06 (s, 3H), 3.95 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 148.8, 147.6, 130.7, 129.9, 129.1, 129.0, 128.7, 128.5, 125.2, 123.7, 123.5, 123.4, 123.2, 115.8, 115.5, 102.8, 101.8, 97.2, 56.8, 56.2 ppm; HRMS (ESI) calcd for $C_{25}H_{18}F_3N_4O_2$ [M + H] 463.1381, found 463.1371.

12-Chloro-1-(p-tolyl)indolo[1,2-a][1,2,3]triazolo[5,1-c]-quinoxaline (**3e**): gray fluffy solid; R_f = 0.58 (10/90 ethyl acetate/hexane); yield 67% (0.165 g); mp 206−208 °C; FT-IR (KBr) 3425, 1625, 1459, 1217, 1158 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.67 (d, J = 7.9 Hz, 1H), 8.38 (d, J = 8.3 Hz, 1H), 8.16 (d, J = 8.8 Hz, 1H), 7.78 (d, J = 7.6 Hz, 2H), 7.68 (s, 1H), 7.60 (t, J = 7.2 Hz, 1H), 7.48−7.36 (m, 4H), 7.18 (s, 1H), 2.49 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 143.5, 139.3, 132.4, 131.2, 129.8, 128.8, 128.6, 127.8, 127.6, 126.5, 125.0, 124.5, 123.7, 122.4, 121.4, 118.1, 116.2, 114.6, 99.9, 21.6 ppm; HRMS (ESI) calcd for $C_{23}H_{16}ClN_4$ [M + H] 383.1063, found 383.1061.

6-Bromo-12-chloro-1-(p-tolyl)indolo[1,2-a][1,2,3]triazolo[5,1-c]-quinoxaline (**3f**): gray fluffy solid; R_f = 0.56 (10/90 ethyl acetate/hexane); yield 62% (0.153 g); mp 195−197 °C; FT-IR (KBr) 3041, 1663, 1465, 1216, 1187 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.67 (d, J = 8.1 Hz, 1H), 8.39 (d, J = 8.4 Hz, 1H), 8.17 (d, J = 9.0 Hz, 1H), 7.79 (d, J = 8.0 Hz, 2H), 7.68 (d, J = 1.9 Hz, 1H), 7.61 (t, J = 8.3 Hz, 1H), 7.47 (t, J = 7.7 Hz, 1H), 7.41−7.38 (m, 2H), 7.18 (s, 1H), 2.50 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 143.4, 139.2, 132.3, 131.1, 129.8, 128.7, 128.5, 127.7, 127.5, 126.3, 124.9, 124.4, 123.6, 122.3, 121.3, 118.0, 116.1, 114.5, 99.8, 21.6 ppm; HRMS (ESI) calcd for $C_{23}H_{15}ClBrN_4$ [M + H] 461.0168, found 461.0176.

1-Phenylindolo[1,2-a][1,2,3]triazolo[5,1-c]quinoxaline (**3g**): gray fluffy solid; R_f = 0.58 (10/90 ethyl acetate/hexane); yield 70% (0.172 g); mp 168−170 °C; FT-IR (KBr) 3400, 1613, 1385, 1216, 1157 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.70 (d, J = 8.0 Hz, 1H), 8.51 (d, J = 8.3 Hz, 1H), 8.29 (d, J = 8.5 Hz, 1H), 7.96 (d, J = 7.2 Hz, 2H), 7.76 (d, J = 7.8 Hz, 1H), 7.63 (t, J = 7.8 Hz, 3H), 7.56 (d, J = 7.3 Hz, 1H), 7.48 (t, J = 7.5 Hz, 2H), 7.37 (t, J = 7.5 Hz, 1H), 7.28 (d, J = 3.8 Hz, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 142.8, 133.8, 130.9, 129.7, 129.0, 128.8, 128.5, 127.8, 124.8, 124.4, 124.3, 123.4, 123.0, 122.8, 122.0, 117.7, 116.2, 113.5, 100.6 ppm; HRMS (ESI) calcd for $C_{22}H_{15}N_4$ [M + H] 335.1296, found 335.1291.

6-Fluoro-1-phenylindolo[1,2-a][1,2,3]triazolo[5,1-c]quinoxaline (**3h**): gray fluffy solid; R_f = 0.54 (10/90 ethyl acetate/hexane); yield 68% (0.168 g); mp 179−181 °C; FT-IR (KBr) 3427, 1645, 1468, 1275, 1156 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.95 (d, J = 1.4 Hz, 1H), 8.57 (d, J = 8.8 Hz, 1H), 8.24 (d, J = 8.6 Hz, 1H), 7.93−7.91 (m, 2H), 7.87−7.84 (m, 1H), 7.76 (d, J = 7.8 Hz, 1H), 7.63−7.59 (m, 2H), 7.56−7.48 (m, 2H), 7.39 (t, J = 7.2 Hz, 1H), 7.31 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 143.3, 134.2, 130.6, 130.2, 129.3, 129.1, 128.9, 126.9, 126.5, 125.5, 125.4, 125.2, 124.9, 123.6, 123.5, 123.0, 122.6, 116.7, 115.6, 115.5, 113.6, 102.0 ppm; HRMS (ESI) calcd for $C_{22}H_{14}FN_4$ [M + H] 353.1202, found 353.1214.

1-Phenyl-6-(trifluoromethyl)indolo[1,2-a][1,2,3]triazolo[5,1-c]-quinoxaline (**3i**): gray fluffy solid; R_f = 0.58 (10/90 ethyl acetate/hexane); yield 60% (0.148 g); mp 209−211 °C; FT-IR (KBr) 3401, 1627, 1384, 1232, 1158 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.95 (d, J = 1.6 Hz, 1H), 8.58 (d, J = 8.8 Hz, 1H), 8.25 (d, J = 8.4 Hz, 1H), 7.93−7.91 (m, 2H), 7.87−7.85 (m, 1H), 7.76 (d, J = 7.8 Hz, 1H), 7.63−7.59 (m, 2H), 7.56−7.48 (m, 2H), 7.39 (t, J = 7.3 Hz, 1H), 7.31 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 143.3, 134.2, 130.5, 130.2, 129.3, 129.1, 128.9, 126.8, 126.5, 125.5, 125.4, 125.2, 124.9, 123.6, 123.5, 123.0, 122.5, 116.7, 115.6, 115.5, 113.6, 102.0 ppm; HRMS (ESI) calcd for $C_{23}H_{14}F_3N_4$ [M + H] 403.1170, found 403.1158.

1-(4-(tert-Butyl)phenyl)indolo[1,2-a][1,2,3]triazolo[5,1-c]-quinoxaline (**3j**): gray fluffy solid; R_f = 0.54 (10/90 ethyl acetate/hexane); yield 72% (0.178 g); mp 169−171 °C; FT-IR (KBr) 3401, 1612, 1387, 1215, 1147 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.68 (d, J = 10.8 Hz, 1H), 8.49 (d, J = 11.2 Hz, 1H), 8.28 (d, J = 11.1 Hz, 1H), 7.88 (d, J = 10.6 Hz, 2H), 7.77 (d, J = 10.4 Hz, 1H), 7.61 (t, J = 9.9 Hz, 3H), 7.45 (d, J = 10 Hz, 2H), 7.37−7.33 (m, 2H), 1.43 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 152.0, 142.8, 133.8, 129.8, 128.4, 128.3, 127.8, 125.8, 125.0, 124.3, 124.2, 123.4, 122.6, 122.0, 117.7, 116.1, 113.4, 100.6, 34.8, 31.3 ppm; HRMS (ESI) calcd for $C_{26}H_{23}N_4$ [M + H] 391.1922, found 391.1920.

1-(4-(tert-Butyl)phenyl)-6-(trifluoromethyl)indolo[1,2-a][1,2,3]-triazolo[5,1-c]quinoxaline (**3k**): gray fluffy solid; R_f = 0.56 (10/90 ethyl acetate/hexane); yield 65% (0.161 g); mp 165−167 °C; FT-IR (KBr) 3400, 1627, 1462, 1386, 1215, 1184 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.68 (s, 1H), 8.49 (d, J = 8.4 Hz, 1H), 8.28 (d, J = 8.5 Hz, 1H), 7.88 (d, J = 8.2 Hz, 2H), 7.77 (d, J = 7.8 Hz, 1H), 7.62 (d, J = 8.3 Hz, 2H), 7.45 (t, J = 7.4 Hz, 2H), 7.35 (d, J = 7.5 Hz, 1H), 7.32 (s, 1H), 1.44 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$ + DMSO-d_6): δ 152.2, 143.1, 134.1, 130.0, 128.6, 128.5, 128.0, 126.0, 125.2, 124.6, 124.4, 123.7, 122.9, 122.8, 122.2, 117.9, 116.4, 113.7, 100.8, 35.1, 31.6 ppm; HRMS (ESI) calcd for $C_{27}H_{22}F_3N_4$ [M + H] 459.1796, found 459.1802.

6-Bromo-1-(4-(tert-butyl)phenyl)indolo[1,2-a][1,2,3]triazolo[5,1-c]quinoxaline (**3l**): gray fluffy solid; R_f = 0.56 (10/90 ethyl acetate/hexane); yield 70% (0.175 g); mp 170−172 °C; FT-IR (KBr) 3408, 1617, 1385, 1245, 1167 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.96 (d, J = 0.9 Hz, 1H), 8.60 (d, J = 8.8 Hz, 1H), 8.27 (d, J = 8.6 Hz, 1H), 7.88−7.86 (m, 3H), 7.80 (d, J = 7.8 Hz, 1H), 7.63 (d, J = 8.3 Hz, 2H), 7.53−7.50 (m, 1H), 7.42−7.39 (m, 2H), 1.44 (s, 9H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$): δ 153.1, 152.5, 143.8, 143.4, 134.2, 130.3, 128.5, 127.6, 126.8, 126.1, 125.4, 125.1, 123.6, 122.8, 122.6, 116.7, 115.5, 113.6, 102.1, 35.1, 31.5 ppm; HRMS (ESI) calcd for $C_{26}H_{22}BrN_4$ [M + H] 469.1027, found 469.1034.

6-((4-(tert-Butyl)phenyl)ethynyl)-5-(2-nitrophenyl)-5H-[1,3]-dioxolo[4,5-f]indole (**1a**): yellow solid; R_f = 0.54 (10/90 ethyl acetate/hexane); yield 80% (0.276 g); mp 102−104 °C; FT-IR (KBr) 3400, 3021, 2962, 2401, 1608, 1533, 1466, 1395 cm^{-1}; ^1H NMR (400

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MHz, $CDCl_3$): δ 8.17−8.14 (m, 1H), 7.79−7.75 (m, 1H), 7.64−7.60 (m, 2H), 7.27 (t, *J* = 8.4 Hz, 2H), 7.20 (d, *J* = 8.4 Hz, 2H), 6.99 (s, 1H), 6.86 (s, 1H), 6.53 (s, 1H), 5.94−5.92 (m, 2H), 1.27 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 151.8, 146.9, 144.3, 133.7, 132.9, 131.6, 131.1, 130.9, 129.1, 125.6, 125.3, 121.9, 120.8, 119.3, 110.3, 101.0, 99.4, 95.6, 90.8, 79.6, 34.8, 31.1 ppm; HRMS (ESI) calcd for $C_{27}H_{23}N_2O_4$ [M + H] 439.1657, found 439.1649.

5-(2-Nitrophenyl)-6-(phenylethynyl)-5H-[1,3]dioxolo[4,5-f]indole (**1b**): yellow solid; R_f = 0.56 (10/90 ethyl acetate/hexane); yield 79% (0.289 g); mp 99−101 °C; FT-IR (KBr) 3401, 3019, 2400, 1653, 1543,1476 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.19−8.16 (m, 1H), 7.81−7.77 (m, 1H), 7.67−7.62 (m, 2H), 7.26 (s, 5H), 7.00 (s, 1H), 6.89 (d, *J* = 0.52 Hz, 1H), 6.54 (s, 1H), 5.96−5.94 (m, 2H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 147.1, 144.5, 133.8, 133.1, 131.7, 131.2, 129.3, 128.5, 128.4, 125.8, 122.5, 122.0, 120.7, 110.7, 101.2, 99.5, 95.6, 91.0, 80.4 ppm; HRMS (ESI) calcd for $C_{23}H_{15}N_2O_4$ [M + H] 383.1031, found 383.1026.

5-(4-Fluoro-2-nitrophenyl)-6-(phenylethynyl)-5H-[1,3]dioxolo-[4,5-f]indole (**1c**): pale yellow solid; R_f = 0.58 (10/90 ethyl acetate/hexane); yield 77% (0.290 g); mp 102−104 °C; FT-IR (KBr) 3402, 3021, 2965, 2401, 1613, 1537, 1490, 1383 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.45 (d, *J* = 1.6 Hz, 1H), 8.06−8.03 (m, 1H), 7.83 (d, *J* = 8.2 Hz, 1H), 7.30−7.27 (m, 5H), 7.00 (s, 1H), 6.93 (s, 1H), 6.56 (s, 1H), 5.98−5.96 (m, 2H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 147.5, 146.6, 144.9, 134.8, 132.6, 131.9, 131.3, 130.5, 128.9, 128.5, 123.5, 123.4, 122.3, 122.2, 120.4, 111.9, 101.4, 99.8, 96.2, 90.8, 79.8 ppm; HRMS (ESI) calcd for $C_{23}H_{14}FN_2O_4$ [M + H] 401.0937, found 401.0931.

2-((4-(tert-Butyl)phenyl)ethynyl)-5,6-dimethoxy-1-(2-nitrophenyl)-1H-indole (**1d**): yellow solid; R_f = 0.54 (10/90 ethyl acetate/hexane); yield 82% (0.280 g); mp 101−103 °C; FT-IR (KBr) 3411, 3019, 1626, 1532, 1385 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.36−8.33 (m, 1H), 8.00−7.96 (m, 1H), 7.86−7.80 (m, 2H), 7.47 (d, *J* = 8.5 Hz, 2H), 7.43 (s, 1H), 7.39 (d, *J* = 8.5 Hz, 2H), 7.08 (s, 1H), 6.72 (s, 1H), 4.12 (s, 3H), 3.99 (s, 3H), 1.46 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 151.9, 149.0, 147.0, 146.5, 133.8, 132.1, 131.8, 131.2, 131.0, 129.0, 125.8, 125.4, 120.8, 120.6, 119.5, 110.1, 102.5, 95.7, 92.9, 79.9, 56.4, 56.3, 34.9, 31.2 ppm; HRMS (ESI) calcd for $C_{28}H_{27}N_2O_4$ [M + H] 455.1970, found 455.1962.

5,6-Dimethoxy-1-(2-nitro-4-(trifluoromethyl)phenyl)-2-(phenylethynyl)-1H-indole (**1e**): yellow solid; R_f = 0.56 (10/90 ethyl acetate/hexane); yield 79% (0.332 g); mp 97−99 °C; FT-IR (KBr) 3401, 3020, 2957, 2406, 1633, 1536, 1484, 1387 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.44 (d, *J* = 3.4 Hz, 1H), 8.07−8.05 (m, 1H), 7.87 (d, *J* = 8.3 Hz, 1H), 7.30 (s, 5H), 7.08 (s, 1H), 6.96 (s, 1H), 6.56 (s, 1H), 3.95 (s, 3H), 3.48 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 149.1, 147.0, 146.5, 133.8, 132.2, 131.7, 131.2, 129.1, 128.5, 128.4, 125.8, 122.6, 120.8, 120.3, 110.4, 102.5, 95.5, 92.9, 80.6, 56.4, 56.3 ppm; HRMS (ESI) calcd for $C_{25}H_{18}F_3N_2O_4$ [M + H] 467.1218, found 467.1210.

5,6-Dimethoxy-1-(2-nitrophenyl)-2-(phenylethynyl)-1H-indole (**1f**): yellow solid; R_f = 0.58 (10/90 ethyl acetate/hexane); yield 81% (0.290 g); mp 103−105 °C; FT-IR (KBr) 3407, 3022, 1638, 1533, 1384 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.17−8.15 (m, 1H), 7.82−7.78 (m, 1H), 7.68−7.62 (m, 2H), 7.25 (s, 5H), 7.06 (s, 1H), 6.91 (s, 1H), 6.54 (s, 1H), 3.93 (s, 3H), 3.81 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 149.0, 146.9, 146.4, 133.7, 132.1, 131.6, 129.0, 128.3, 125.6, 122.4, 120.6, 120.2, 110.3, 102.3, 95.4, 92.8, 80.5, 56.2, 56.1 ppm; HRMS (ESI) calcd for $C_{24}H_{19}N_2O_4$ [M + H] 399.1344, found 399.1347.

5-Chloro-1-(2-nitrophenyl)-2-(p-tolylethynyl)-1H-indole (**1g**): pale yellow solid; R_f = 0.64 (10/90 ethyl acetate/hexane); yield 74% (0.269 g); mp 91−93 °C; FT-IR (KBr) 3406, 2958, 2400, 1606, 1533, 1476, 1392 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.19−8.17 (m, 1H), 7.82−7.77 (m, 1H), 7.67−7.61 (m, 3H), 7.19−7.16 (m, 3H), 7.09 (d, *J* = 7.9 Hz, 2H), 7.01 (d, *J* = 8.7 Hz, 1H), 6.92 (d, *J* = 0.5 Hz, 1H), 2.32 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 146.9, 139.3, 135.8, 133.9, 131.4, 131.2, 129.5, 129.2, 129.1, 127.2, 125.8, 124.5, 123.7, 120.6, 118.8, 110.8, 109.4, 96.8, 79.0, 21.6 ppm; HRMS (ESI) calcd for $C_{23}H_{16}ClN_2O_2$ [M + H] 387.0900, found 387.0892.

1-(4-Bromo-2-nitrophenyl)-5-chloro-2-(p-tolylethynyl)-1H-indole (**1h**): light red solid; R_f = 0.68 (10/90 ethyl acetate/hexane); yield 71% (0.310 g); mp 102−104 °C; FT-IR (KBr) 3402, 3022, 2400, 1653, 1532, 1478, 1332 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.58 (d, *J* = 2.2 Hz, 1H), 8.20−8.17 (m, 1H), 7.88 (d, *J* = 1.8 Hz, 1H), 7.77 (s, 1H), 7.52−7.44 (m, 4H), 7.39 (d, *J* = 8.0 Hz, 2H), 7.25 (d, *J* = 8.7 Hz, 1H), 2.61 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 147.0, 139.6, 137.0, 135.6, 132.4, 131.5, 130.3, 129.3, 129.2, 128.9, 127.5, 124.7, 123.5, 122.6, 120.8, 118.7, 110.7, 109.9, 97.1, 78.7, 21.7 ppm; HRMS (ESI) calcd for $C_{23}H_{15}BrClN_2O_2$ [M + H] 465.0005, found 464.9996.

1-(2-Nitrophenyl)-2-(phenylethynyl)-1H-indole (**1i**): yellow solid; R_f = 0.62 (10/90 ethyl acetate/hexane); yield 75% (0.292 g); mp 89−91 °C; FT-IR (KBr) 3406, 3021, 2401, 1627, 1545, 1449, 1383 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.40 (d, *J* = 1.3 Hz, 1H), 7.98−7.96 (m, 1H), 7.77 (d, *J* = 8.2 Hz, 1H), 7.62−7.60 (m, 1H), 7.29−7.24 (m, 5H), 7.23−7.15 (m, 3H), 7.06 (d, *J* = 8.1 Hz, 1H), 7.00 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 146.5, 137.1, 134.8, 132.0, 131.5, 130.5, 130.4, 129.1, 128.5, 128.3, 124.9, 123.5, 123.4, 122.2, 121.7, 111.7, 109.6, 96.6, 79.6 ppm; HRMS (ESI) calcd for $C_{22}H_{15}N_2O_2$ [M + H] 339.1133, found 339.1139.

1-(4-Fluoro-2-nitrophenyl)-2-(phenylethynyl)-1H-indole (**1j**): yellow solid; R_f = 0.62 (10/90 ethyl acetate/hexane); yield 73% (0.295 g); mp 104−106 °C; FT-IR (KBr) 3401, 3020, 2959, 2400, 1604, 1384, 1215 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.89−7.86 (m, 1H), 7.63−7.60 (m, 3H), 7.50−7.45 (m, 1H), 7.24 (s, 1H), 7.20 (s, 2H), 7.18−7.15 (m, 2H), 7.06−6.98 (m, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 137.6, 133.2, 133.1, 131.5, 129.0, 128.5, 128.1, 124.6, 122.1, 121.8, 121.6, 121.2, 121.0, 113.6, 113.4, 110.7, 109.6, 96.1, 80.0 ppm; HRMS (ESI) calcd for $C_{22}H_{14}FN_2O_2$ [M + H] 357.1039, found 357.1027.

1-(2-Nitro-4-(trifluoromethyl)phenyl)-2-(phenylethynyl)-1H-indole (**1k**): yellow solid; R_f = 0.62 (10/90 ethyl acetate/hexane); yield 76% (0.290 g); mp 65−67 °C; FT-IR (KBr) 3402, 3021, 2401, 1628, 1543, 1384 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.65 (d, *J* = 1.4 Hz, 1H), 8.25−8.22 (m, 1H), 8.04 (d, *J* = 8.2 Hz, 1H), 7.86 (d, *J* = 7.3 Hz, 1H), 7.50 (s, 5H), 7.47−7.40 (m, 3H), 7.31 (d, *J* = 7.9 Hz, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 146.5, 137.1, 134.8, 132.0, 131.5, 130.5, 129.1, 128.6, 128.3, 124.9, 123.5, 123.4, 122.2, 121.9, 121.8, 121.7, 111.7, 109.6, 96.6, 79.6 ppm; HRMS (ESI) calcd for $C_{23}H_{14}F_3N_2O_2$ [M + H] 407.1007, found 407.1002.

1-(4-Methyl-2-nitrophenyl)-2-(phenylethynyl)-1H-indole (**1l**): yellow solid; R_f = 0.60 (10/90 ethyl acetate/hexane); yield 78% (0.295 g); mp 94−96 °C; FT-IR (KBr) 3401, 3020, 2958, 2401, 1603, 1527, 1453, 1348 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.07 (d, *J* = 8.3 Hz, 1H), 7.63 (d, *J* = 7.4 Hz, 1H), 7.41−7.36 (m, 2H), 7.29−7.23 (m, 5H), 7.22−7.14 (m, 2H), 7.10 (d, *J* = 7.7 Hz, 1H), 7.00 (s, 1H), 2.47 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 145.3, 144.4, 137.3, 131.5, 131.4, 131.3, 129.6, 128.6, 128.3, 127.9, 125.7, 124.2, 122.2, 121.9, 121.4, 121.3, 110.2, 109.8, 95.7, 80.1, 21.4 ppm; HRMS (ESI) calcd for $C_{23}H_{17}N_2O_2$ [M + H] 353.1290, found 353.1285.

2-((4-(tert-Butyl)phenyl)ethynyl)-1-(2-nitrophenyl)-1H-indole (**1m**): yellow solid; R_f = 0.60 (10/90 ethyl acetate/hexane); yield 88% (0.298 g); mp 67−69 °C; FT-IR (KBr) 3400, 3021, 2959, 1608, 1533, 1385, 1216 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.45−8.42 (m, 1H), 8.06−8.02 (m, 1H), 7.92−7.86 (m, 3H), 7.55 (d, *J* = 8.4 Hz, 2H), 7.50−7.42 (m, 5H), 7.34 (d, *J* = 7.8 Hz, 1H), 1.53 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 152.3, 147.1, 137.5, 133.9, 131.7, 131.4, 131.3, 129.2, 128.2, 125.9, 125.5, 124.3, 122.4, 121.6, 121.5, 119.3, 110.3, 109.9, 96.2, 79.6, 35.0, 31.3 ppm; HRMS (ESI) calcd for $C_{26}H_{23}N_2O_2$ [M + H] 395.1759, found 395.1755.

2-((4-(tert-Butyl)phenyl)ethynyl)-1-(4-fluoro-2-nitrophenyl)-1H-indole (**1n**): yellow solid; R_f = 0.62 (10/90 ethyl acetate/hexane); yield 80% (0.301 g); mp 79−81 °C; FT-IR (KBr) 3402, 2927, 2402, 1633, 1535, 1487 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.18−8.16 (m, 1H), 7.92−7.89 (m, 2H), 7.78−7.74 (m, 1H), 7.59−7.57 (m, 2H), 7.51−7.49 (m, 3H), 7.48−7.46 (m, 1H), 7.45−7.43 (m, 1H), 7.31−7.29 (m, 1H), 1.55 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 152.4, 137.5, 133.1, 133.0, 131.2, 128.1, 128.0, 127.9, 125.5, 124.4, 122.4, 121.7, 121.5, 121.2, 121.0, 119.1, 113.6, 113.3, 110.4, 109.6, 96.3, 79.3, 35.0,

31.2 ppm; HRMS (ESI) calcd for $C_{26}H_{22}FN_2O_2$ [M + H] 413.1665, found 413.1651.

*2-((4-(tert-Butyl)phenyl)ethynyl)-1-(2-nitro-4-(trifluoromethyl)-phenyl)-1H-indole (**1o**):* yellow solid; R_f = 0.62 (10/90 ethyl acetate/hexane); yield 82% (0.300 g); mp 109−111 °C; FT-IR (KBr) 3407, 3020, 2961, 2401, 1628, 1545, 1451, 1382 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.44 (s, 1H), 8.02 (d, J = 8.3 Hz, 1H), 7.83 (d, J = 8.2 Hz, 1H), 7.64 (d, J = 7.2 Hz, 1H), 7.32−7.30 (m, 4H), 7.23 (d, J = 1.4 Hz, 2H), 7.09 (d, J = 7.5 Hz, 1H), 7.02 (s, 1H), 1.27 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 152.2, 147.0, 137.5, 133.8, 131.7, 131.4, 131.2, 129.2, 128.1, 125.8, 125.5, 124.3, 122.4, 121.6, 121.4, 119.2, 110.2, 109.8, 96.2, 79.5, 35.0, 31.2 ppm; HRMS (ESI) calcd for $C_{27}H_{22}F_3N_2O_2$ [M + H] 463.1633, found 463.1630.

*1-(4-Bromo-2-nitrophenyl)-2-((4-(tert-butyl)phenyl)ethynyl)-1H-indole (**1p**):* light red solid; R_f = 0.60 (10/90 ethyl acetate/hexane); yield 82% (0.305 g); mp 91−93 °C; FT-IR (KBr) 3399, 3020, 2962, 2401, 1603, 1537, 1490 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.56 (s, 1H), 8.15−8.13 (m, 1H), 7.89 (d, J = 7.5 Hz, 1H), 7.78 (d, J = 8.4 Hz, 1H), 7.58 (d, J = 8.3 Hz, 2H), 7.53−7.43 (m, 5H), 7.32 (d, J = 7.9 Hz, 1H). 1.55 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 152.5, 147.1, 137.3, 136.9, 132.6, 131.4, 130.8, 128.9, 128.3, 125.6, 124.6, 122.2, 122.1, 121.9, 121.6, 119.1, 110.8, 109.7, 96.5, 79.2, 35.0, 31.3 ppm; HRMS (ESI) calcd for $C_{26}H_{22}BrN_2O_2$ [M + H] 473.0864, found 473.0857.

■ ASSOCIATED CONTENT

Supporting Information

Figures giving ^1H and ^{13}C NMR spectra of all final compounds and tables and a CIF file giving X-ray crystallographic data of **2a**. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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(17) The CCDC file 958098 (**2a**) contains supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

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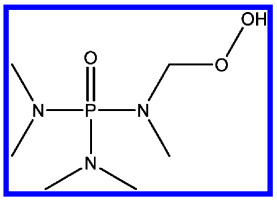
(25) See the Supporting Information for a plausible mechanism involving HMPA peroxide mediated formation of **2**.



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