JOC The Journal of Organic Chemistry

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NaOH-Mediated Direct Synthesis of Quinoxalines from *o*-Nitroanilines and Alcohols via a Hydrogen-Transfer Strategy

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Cite This: https://dx.doi.org/10.1021/acs.joc.0c02453 Read Online

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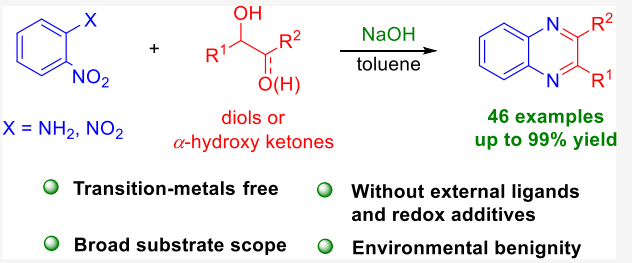
ABSTRACT: A NaOH-mediated sustainable synthesis of functionalized quinoxalines is disclosed via redox condensation of *o*-nitroamines with diols and α-hydroxy ketones. Under optimized conditions, various *o*-nitroamines and alcohols are well tolerated to generate the desired products in 44−99% yields without transition metals and external redox additives.

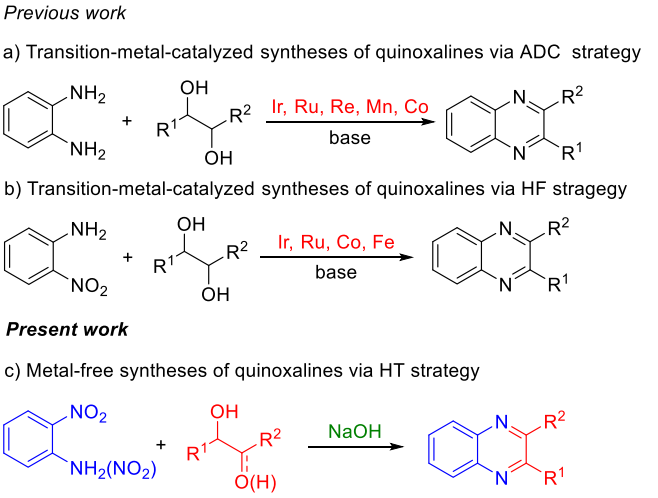


INTRODUCTION

As an important class of nitrogen heterocycles, quinoxalines are recognized as valuable synthetic targets because of their wide existence in medicinally important and biologically active compounds.[1] Meanwhile, quinoxaline chromophores have demonstrated diverse applications in materials science for the development of novel organic optoelectronics.[2] Consequently, considerable efforts have been made to access substituted quinoxaline scaffolds.[3] The conventional preparation of quinoxalines usually involves the annulation of *o*-diaminobenzenes with ketone derivatives, alkene, alkyne, and other reagents.[4] In addition, transition-metal-catalyzed oxidative cyclization of *N*-arylenamines with azides, nitromethane, and nitrites has been developed.[5] Recently, quinoxalines could also be prepared utilizing *o*-diisocyanoarenes as radical acceptors via a radical cascade cyclization strategy.[6] Despite the above progress, the development of efficient and environmentally friendly methods using simple and readily available starting materials is still desired.

The past few decades have witnessed the thriving development of acceptorless dehydrogenation coupling (ADC) and hydrogen-transfer (HT) strategy, which plays an important role in the construction of C−C bonds,[7] C−N bonds,[8] and heterocycles.[9] Meanwhile, biomass-derived alcohols are widely utilized as coupling partners as they are inexpensive, green, and readily available with great structural diversity. In this context, the dehydrogenative condensation between aromatic amines and diols was reported using Ir, Ru, Mn, and Co complexes, which represents an efficient and sustainable synthetic route to access quinoxalines (Scheme 1a).[10] Compared with aromatic diamines, nitroarenes are more stable functionalized materials, which could react with other reducing components to form various nitrogen-containing heterocycles.[11] Recently, Zhang, Kundu, and Nguyen groups have independently reported the syntheses of quinoxalines via transfer hydrogenation between *o*-nitroanilines and vicinal diols catalyzed by Ru, Ir, Co, Fe, and Ni transition metals (Scheme 1b).[10c,f,12] Nevertheless, most of the above protocols employ transition-metal catalysts, special ligands, or external additives, which make them difficult to be applied in industrial manufacturing.

Scheme 1. Strategies for Syntheses of Quinoxalines



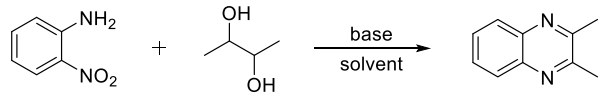
Received: October 15, 2020

To overcome the above limitations, base-mediated C−C and C−N coupling[13] have been disclosed to realize α-alkylation of ketones,[14] β-alkylation of alcohols,[15] N-alkylation of amines,[16] and other transformation.[17] On the basis of the above literature and our experience in ADC and HT reactions,[18] we herein reported a NaOH-mediated one-pot synthesis of substituted quinoxalines through redox condensation of *o*-nitroanilines and vicinal diols or α-hydroxy ketones (Scheme 1c). In this synthetic protocol, alcohol and the nitro group serve as the hydrogen donor and hydrogen acceptor, respectively, generating water as the only byproduct. Meanwhile, excess alcohols are required because each alcohol function provides only two electrons, while the reduction of a nitro group requires six electrons.[12c]

RESULTS AND DISCUSSION

We commenced our study by investigating the model reaction of *o*-nitroaniline (**1a**) and 2,3-butandiol (**2a**) under various reaction conditions (Table 1). To our delight, quinoxaline **3a** was isolated in 71% yield in the presence of KO^{t}Bu (0.5 equiv) in toluene (1 mL) at 100 °C for 12 h under Ar (entry 1, Table 1). The utilization of NaO^{t}Bu gave **3a** in 74% yield with slightly higher efficiency (entry 1, Table 1). Subsequently, other strong bases, such as KOH, NaOH, and CsOH·H_2O, were also evaluated, indicating that NaOH (of AR grade and 96% purity was used unless otherwise noted) was the best choice to provide product **3a** in 90% yield (entry 3−5, Table 1). Next, various solvents, such as *o*-xylene, dioxane, and ^{t}AmOH, were examined, which all gave **3a** in decreased yield (entry 6−8, Table 1). Interestingly, quinoxaline **3a** could also be isolated in 76% yield without any solvent (entry 9, Table 1). To improve the reaction efficiency, the effects of reaction temperature and time were studied. It was found that the desired product **3a** could be isolated in 92% yield at 120 °C for 3 h (entry 10, Table 1). When the reaction was carried out at 150 °C for 1 h, similar results could also be obtained (entry 11, Table 1). Furthermore, a substantially decreased yield was observed when performing the reaction under air (entry 12, Table 1). As the base-promoted oxidation of alcohols to carbonyl compounds under an inert atmosphere is also well-developed via a transfer dehydrogenation process (MPV-O mechanism),[13,14,16c,17b,19] the intervention of oxygen as an oxidizing agent might not be involved in the current redox condensation process as *o*-nitroanilines serve both as the hydride acceptor and reactant. When the dosage of NaOH was decreased to 0.3 equiv, product **3a** was obtained in 37% yield, which implies that the dosage of NaOH plays an important role in determining the reaction efficiency (entry 13, Table 1).[20] No product was isolated in the absence of NaOH, indicating the necessity of base (entry 14, Table 1). Finally, a control experiment using new glassware and 4 N grade NaOH was conducted, which also gave product **3a** in 91% yield (entry 15, Table 1). Meanwhile, inductively coupled plasma-atomic emission spectrometry (ICP-AES) measurements of AR grade NaOH were also performed to check the transition-metal residues. The contents of Cr, Mn, Fe, Co, Ni, Cu, Zn, Ru, Rh, Pd, Ir, and Pt were found to be less than the detection limit (0.1 ppm), indicating that the redox condensation between *o*-nitroanilines and alcohols is promoted by NaOH itself rather than trace-metal impurities.

Table 1. Optimization of Reaction Conditions[a]



1a 2a 3a

entry	base	solvent	temp (°C)	time (h)	yield (%)
1	KO^{t}Bu	toluene	100	12	71
2	NaO^{t}Bu	toluene	100	12	74
3	KOH	toluene	100	12	49
4	NaOH	toluene	100	12	90
5	CsOH·H_2O	toluene	100	12	40
6	NaOH	*o*-xylene	100	12	74
7	NaOH	dioxane	100	12	33
8	NaOH	^{t}AmOH	100	12	48
9	NaOH	neat	100	12	76
10	**NaOH**	**toluene**	**120**	**3**	**92**
11	NaOH	toluene	150	1	90
12[b]	NaOH	toluene	120	3	24
13[c]	NaOH	toluene	120	3	37
14		toluene	120	3	0
15[d]	NaOH	toluene	120	3	92

[a]Reaction conditions: **1a** (0.5 mmol), **2a** (2.0 mmol), base (0.5 equiv, AR grade, 96% purity), solvent (1.0 mL), under Ar. Isolated yields. [b]Under air. [c]NaOH (0.3 equiv). [d]Virgin glassware and 4 N grade NaOH (99.99% purity) were used. ^{t}AmOH: 2-methyl-2-butanol.

With the optimized conditions in hand, the redox condensation between various *o*-nitroanilines and 2,3-butandiol was investigated (Table 2). To our delight, a series of monosubstituted *o*-nitroanilines bearing OMe, Me, F, Cl, and Br groups at different positions were well tolerated to afford quinoxaline **3a**−**h** in 61−98% yield. For 3-methyl-2-nitroaniline and 6-methyl-2-nitroaniline substrates, the same product **3b** could be obtained in an almost identical yield. However, product **3e** was isolated in much higher yield (98%) starting from 5-chloro-2-nitroaniline. In general, *o*-nitroanilines bearing electron-donating groups at the C4 position provided the corresponding product (**3c**) in higher yields than those of electron-deficient *o*-nitroanilines (**3d**−**f**), which might be ascribed to the enhanced nucleophilicity of the amino group. On the contrary, C5-substituted electron-rich *o*-nitroanilines provided quinoxalines (**3g** and **3h**) in lower yields than the electron-deficient one (**3e**), which could arise from the decreased reducibility of the nitro group. Next, di-substituted *o*-nitroanilines could also react with **2a** to deliver products **3i**−**k** in 63−94% yields.

Encouraged by the above results, the generality and limitations of current protocol were further evaluated through variation of diols (Table 3). Initially, symmetrical aryl- and alkyl-substituted vicinal diols were examined, which gave quinoxalines **4a**−**f** in 52−98% yields. Next, a series of unsymmetrical diols were employed, which required a higher temperature and longer reaction time to provide quinoxalines **4g**−**p** in 48−82% yields. For vicinal diols attached with aryl groups, installation of an electron-rich substituent OMe (**4e**) at the phenyl ring was beneficial, which is probably due to the increased oxidizability of the hydroxyl to carbonyl group. For alkyl-substituted diols, the alkyl chain length has a great influence on reactivity with product **4o** obtained in 82% yield. Finally, the reaction between substituted *o*-nitroanilines and vicinal diols was explored to furnish products **4q**−**z** in 46−98% yield. Notably, when 4 N grade NaOH was utilized, the corresponding products **4a**, **4f**, and **4g** were also obtained in comparable yields.

In addition, various α-hydroxy ketones were also found to be suitable substrates to afford the desired product **4** in 44−99% yield (Table 4). Especially, when electron-rich groups such as

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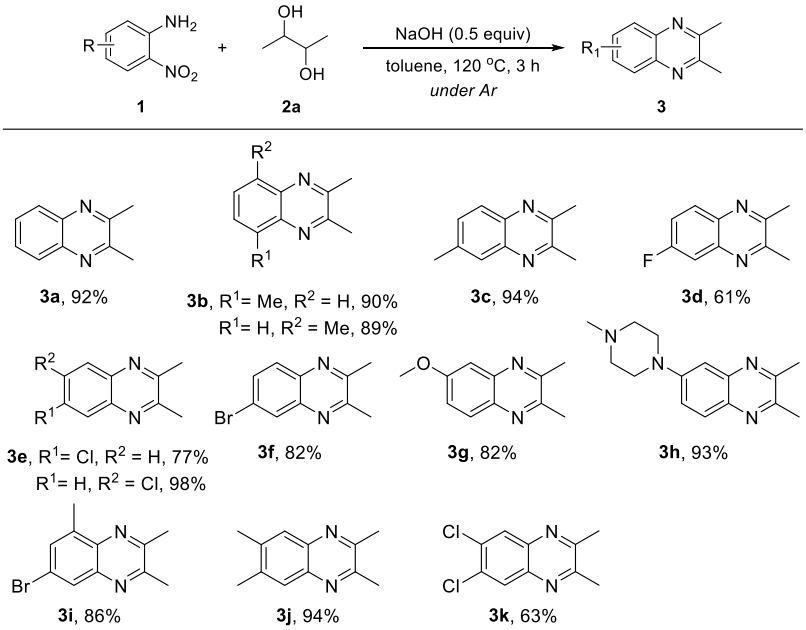
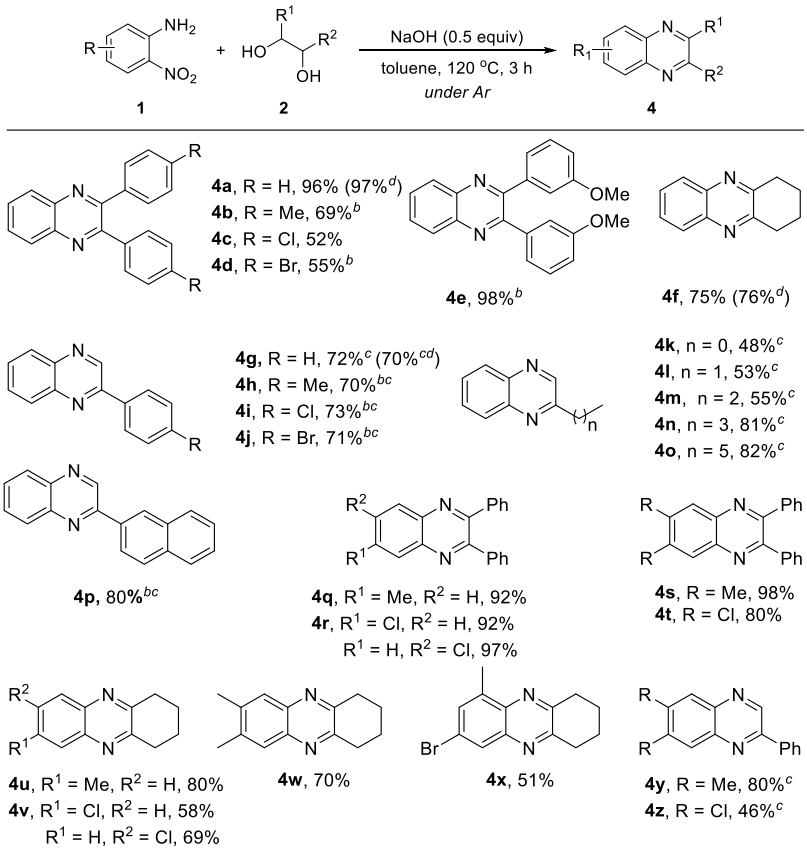
Table 2. Substrate Scope of *o*-Nitroanilines[a]



[a]Reaction conditions: **1** (0.5 mmol), **2a** (2.0 mmol), NaOH (0.5 equiv, AR grade, 96% purity), toluene (1.0 mL), under Ar. Isolated yields.

Table 3. Substrate Scope of *o*-Nitroanilines and Vicinal Diols[a]



[a]Reaction conditions: **1** (0.5 mmol), **2** (2.0 mmol), NaOH (0.5 equiv, AR grade, 96% purity), toluene (1.0 mL), 120 °C, 3 h, under Ar. Isolated yields. [b]**1** (0.1 mmol), **2** (0.4 mmol). [c]150 °C, 12 h. [d]4 N grade NaOH (99.99% purity).

methoxyphenyl and furyl were introduced, quinoxalines **4ab**−**ai** could be obtained in 75−99% yields. Notably, when 4 N grade NaOH was utilized, the corresponding products **4aa** and **4ab** were also obtained in comparable yields.

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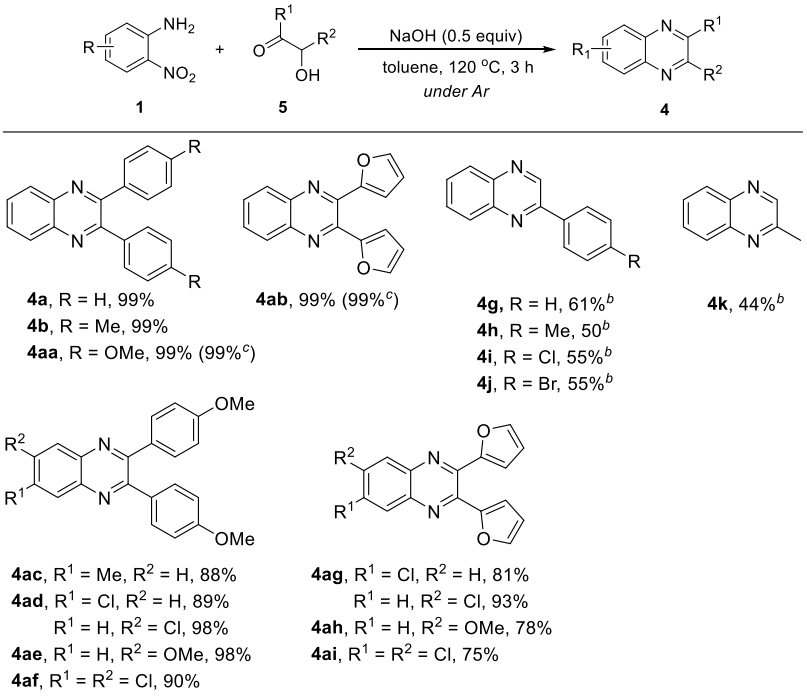
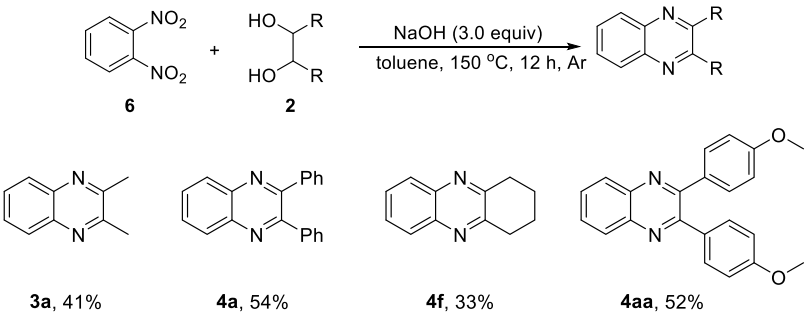
Table 4. Substrate Scope of *o*-Nitroanilines and α-Hydroxy Ketones[a]



[a]Reaction conditions: **1** (0.1 mmol), **5** (0.4 mmol), NaOH (0.5 equiv, AR grade, 96% purity), toluene (1.0 mL), 120 °C, 3 h, under Ar. Isolated yields. [b]150 °C, 12 h. [c]4 N grade NaOH (99.99% purity).

Table 5. Substrate Scope of 1,2-Dinitrobenzene and Vicinal Diols[a]



[a]Reaction conditions: 1,2-dinitrobenzene (0.5 mmol), vicinal (2.0 mmol), NaOH (3.0 equiv, AR grade, 96% purity), toluene (1.0 mL), 150 °C, 12 h, under Ar. Isolated yields.

Notably, 1,2-dinitrobenzene also proved to be a promising substrate, which reacted with various vicinal diols to afford the desired product **3a**, **4a**, **4f**, and **4aa** in 41−52% yield when the reaction was performed at higher temperatures (Table 5). Compared with *o*-nitroanilines, the lack of intramolecular N−H···O interaction and the reduction of two nitro groups could be the reason that requires excess NaOH (3 equiv) to fulfill the transformation.

To demonstrate the synthetic utility of the current strategy, a gram-scale production was performed to give quinoxaline **3a** in 87% yield (Scheme 2). Furthermore, the obtained product **3a** could undergo oxidation, reduction, and transfer hydrogenation to give products **7**, **8**, and **9** in 67, 88, and 96% yields, respectively.

As shown in Table 1 (entries 1−5) and Table S1, base plays an important role in determining the reaction efficiency. The activity of redox condensation between **1a** and **2a** was strongly dependent on the cation involved from LiOH (25%) to CsOH·H_2O (40%), KOH (49%), and NaOH (90%).[16c,20a] Meanwhile, other strong bases, such as NaOMe (31%), NaH (42%), NaO^{t}Bu (71%), and KO^{t}Bu (74%), also generated product **3a** in moderate to good yields, while other weak bases led to decreased or no reaction efficiency (such as Na_2CO_3, 0%).[13,16c,20b] To explore the reaction mechanism, a set of control experiments were conducted (Scheme 3). First, quinoxaline **3a** could be obtained in 86% yield in the presence of both KOH (0.5 equiv) and Na_2CO_3 (0.25 equiv) (Scheme 3a), indicating that the existence of both Na^+ and OH^- is necessary. On the contrary, the combination of NaOH (0.5 equiv) and 15-crown-5 did not led to detectable **3a** (Scheme 3a), which is probably due to the strong binding ability of 15-crown-5 with the sodium cation. In this case, the concentration of Na^+ is decreased in the reaction media, which led to a reduced reaction efficiency.[16c,21] Meanwhile, when ^{n}Bu$_4$NOH was utilized, quinoxaline **3a** could not be detected, indicating that the alkali metal cation is necessary for this reaction. Therefore, the hemiaminal working model could be ruled out in the mechanism.[16b] The above experiment reveals that the reaction rate was largely influenced

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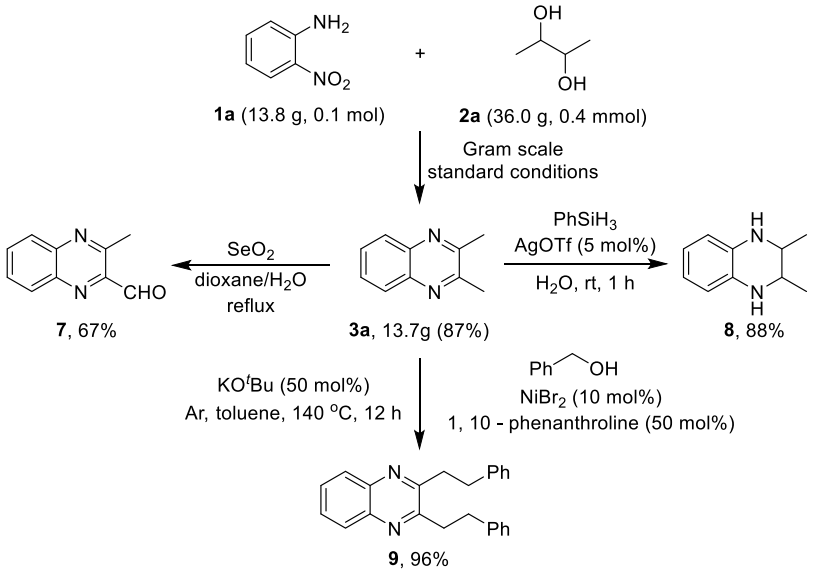
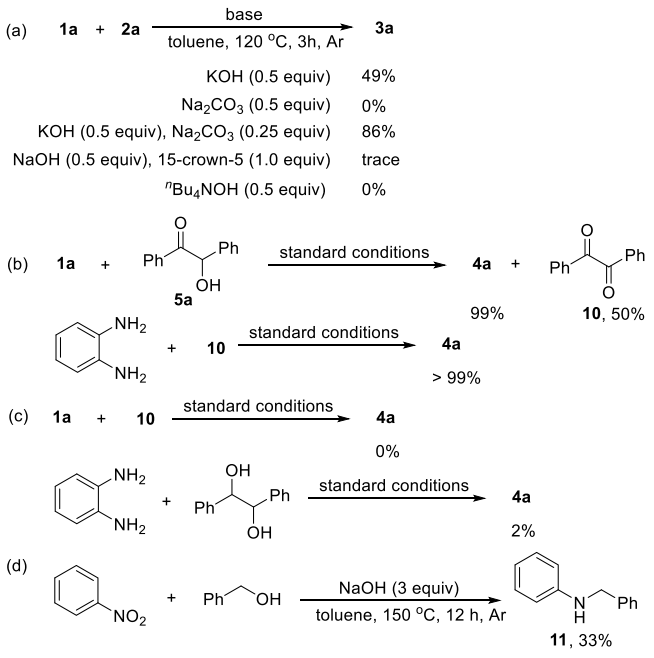
J. Org. Chem. XXXX, XXX, XXX−XXX

Scheme 2. Gram-Scale Synthesis and Derivatization Reactions



Scheme 3. Control Experiments



by the type of base and alkaline cations. The superiority of Na^+ was also highlighted in previous report for the HT of ketones.[20] However, it is still unclear for the mechanistic role of the metal ions. Meanwhile, a relevant role is also played by the solvent, with the apolar, nonprotic toluene affording the highest conversion.[22] Next, the reaction between **1a** and α-hydroxy ketone **5a** gave product **4a** and diketone **10** under the optimized conditions. Meanwhile, condensation between *o*-diamine and **10** provided quinoxaline **4a** in quantitative yield (Scheme 3b), suggesting that benzene-1,2-diamine and diketone **10** might be the potential intermediate. Finally, when *o*-nitroaniline **1a** was treated with diketone **10** or when diol was treated with *o*-diamine, no corresponding product **4a** could be detected (Scheme 3c), implying the integral part of both the hydrogen donor alcohol group and the hydrogen acceptor nitro group to fulfill this transformation. To further verify the hypothesis, the reaction between nitrobenzene and benzyl alcohol was investigated. To our delight, the desired product **11** was isolated in 33% yields using 3.0 equiv NaOH (Scheme 3d).

Based on the above discussion and the relevant literature, a plausible reaction mechanism was proposed (Scheme 4). Initially, deprotonation of diol provided sodium salt **A**, which underwent a redox reaction with *o*-nitroaniline **1a** to afford *o*-nitrosoaniline and α-hydroxy ketone **5a** via the intermediate $\mathbf{TS_B}$. The first reduction of NO_2 to NO has also been verified by DFT calculations, indicating that $\mathbf{TS_B}$ could be the potential intermediate (see the Supporting Information).[23] Furthermore, MPV-type HT between *o*-nitrosoaniline and sodium alkoxide **C** via the intermediate $\mathbf{TS_D}$ would generate diketone **10** and **E**, which reacted with the hydroxyl group of the second diol to give **A** and **F**. Another redox reaction between **A** and **F** would provide benzene-1,2-diamine and α-hydroxy ketone **5a**. Finally, the base-induced intermolecular condensation between diamine and **10** would give the desired quinoxaline **4a**.

CONCLUSIONS

In conclusion, we have developed a novel and facile synthetic methodology to efficiently access quinoxaline via a NaOH-promoted redox-condensation strategy. During the reaction, *o*-nitroanilines and alcohols serve as the hydrogen donors and acceptors, respectively. The current protocol exhibits several unique characteristics, such as a broad substrate scope, mild reaction conditions, and being transition-metal-free. The obtained quinoxalines could further undergo derivatization to afford other value-added chemicals.

EXPERIMENTAL SECTION

General Experimental Details. Unless otherwise mentioned, all reagents were obtained from commercial suppliers and used without further purification. Phenyl-substituted diols and α-hydroxy ketones were synthesized according to previous literature.[24−26] Solvents were dried with standard methods and freshly distilled prior to use if needed. Melting points were determined on an XT4A melting point apparatus and were uncorrected. Flash column chromatography was performed using 200−300 mesh silica gel. Analytical and preparative thin-layer chromatography (TLC) plates coated with commercial silica gel GF254 were used to monitor the reactions and purify the products. ^{1}H NMR, ^{13}C{H} NMR, and ^{19}F{H} NMR spectra were recorded at 400 or 600

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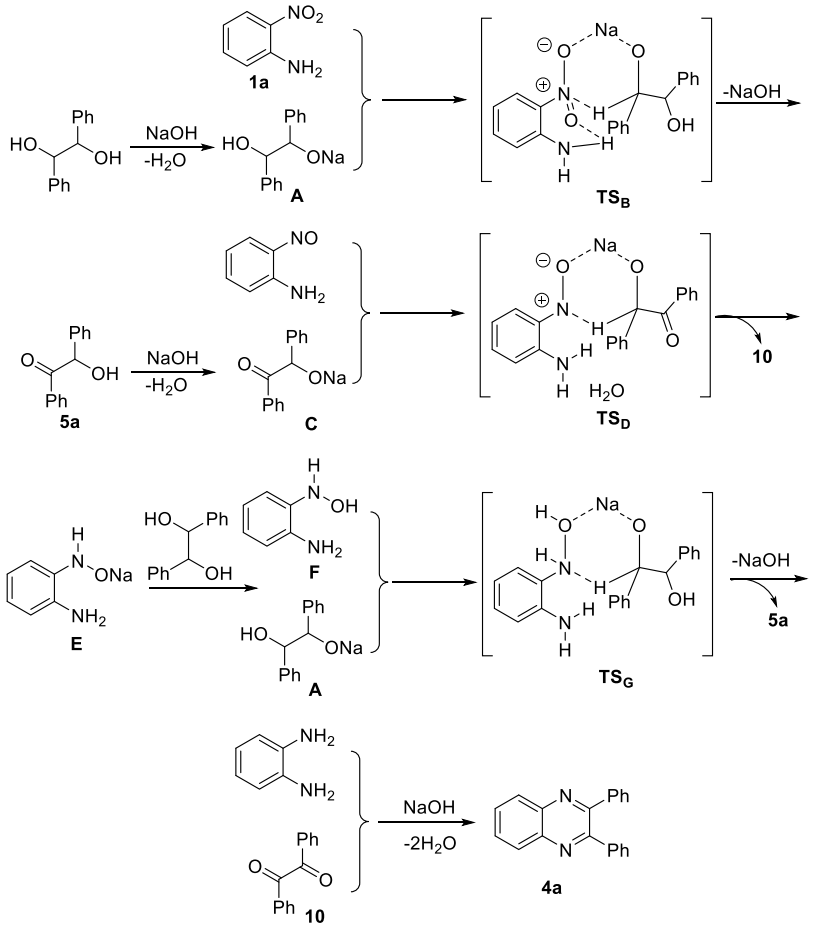
J. Org. Chem. XXXX, XXX, XXX−XXX

Scheme 4. Proposed Reaction Mechanism



MHz, 101 or 151 MHZ, and 376 MHz, respectively, on a Bruker DPX instrument using TMS as an internal standard. Data were reported as follows: chemical shift (δ ppm), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, and m = multiplet), integration, and coupling constants (J) in hertz. HRMS was performed on a Q-Tof micro LC/MS system ESI spectrometer. ICP-AES analysis was conducted on a Shimadzu multitype ICP emission spectrometer (213DFOG/ICP-9820). ICP-MS analysis was conducted on the Agilent 7700s.

General Procedure for the Synthesis of 3 and 4. To an oven-dried 35 mL Ace pressure tube was added **1** (0.5 or 0.1 mmol) or **6** (0.5 mmol), **2** or **5** (2.0 or 0.4 mmol), and NaOH in toluene (1.0 mL) under Ar. The sealed tube was capped and taken out of the glovebox. After stirring in a preheated oil bath at 120 °C for 3 h (or 150 °C for 12 h), the reaction mixture was cooled down to room temperature and directly concentrated under vacuum. The organic residue was purified by preparative TLC to give the desired products **3** and **4**.

*2,3-Dimethylquinoxaline (**3a**).* Purified by analytical TLC on silica gel with DCM/EA (50:1) as an eluent R_f = 0.28; brown solid (72.5 mg, 92% yield from *o*-nitroanilines; 32.4 mg, 41% yield from 1,2-dinitrobenzene). mp: 91−92 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.00−7.96 (m, 2H), 7.96−7.65 (m, 2H), 2.74 (s, 6H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 153.5, 141.1, 128.8, 128.3, 23.2. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{10}H_{11}N_2$, 159.0917; found, 159.0915.

*2,3,5-Trimethylquinoxaline (**3b**).* Purified by analytical TLC on silica gel with DCM/EA (50:1) as an eluent R_f = 0.49; yellow solid (76.5 mg, 89%). mp: 71−72 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.81 (d, J = 8.1 Hz, 1H), 7.75−7.47 (m, 2H), 2.77 (s, 3H), 2.73 (s, 3H), 2.72 (s, 3H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 152.8, 152.2, 141.1, 140.3, 136.7, 128.8, 128.4, 126.1, 23.3, 23.1, 17.1. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{11}H_{13}N_2$, 173.1073; found, 173.1072.

*2,3,6-Trimethylquinoxaline (**3c**).* Purified by analytical TLC on silica gel with DCM/EA (50:1) as an eluent R_f = 0.42; yellow solid (80.8 mg, 94%). mp: 89−90 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.86 (d, J = 8.5 Hz, 1H), 7.75 (s, 1H), 7.49 (dd, J = 8.5, 1.7 Hz, 1H), 2.71 (s, 6H), 2.56 (s, 3H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 153.3, 152.4, 141.2, 139.1, 131.0, 127.8, 127.3, 23.2, 23.1, 21.7. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{11}H_{13}N_2$, 173.1073; found, 173.1072.

*6-Fluoro-2,3-dimethylquinoxaline (**3d**).* Purified by analytical TLC on silica gel with DCM/EA (50:1) as an eluent R_f = 0.45; yellow solid (54.0 mg, 61%). mp: 108−109 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.97 (dd, J = 9.2, 5.7 Hz, 1H), 7.60 (dd, J = 9.3, 2.8 Hz, 1H), 7.35 (td, J = 8.6, 2.7 Hz, 1H), 2.72 (d, J = 3.0 Hz, 6H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 162.1 (C−F, $^1J_{C-F}$ = 249.7 Hz), 154.5, 152.8 (C−F, $^4J_{C-F}$ = 3.3 Hz), 141.7 (C−F, $^3J_{C-F}$ = 12.6 Hz), 138.2, 130.2 (C−F, $^3J_{C-F}$ = 9.8 Hz), 118.9 (C−F, $^2J_{C-F}$ = 25.7 Hz), 112.0 (C−F, $^2J_{C-F}$ = 21.4 Hz), 23.2, 23.0. ^{19}F{H} NMR (376 MHz, $CDCl_3$): δ −110.3. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{10}H_{10}FN_2$, 177.0823; found, 177.0823.

*6-Chloro-2,3-dimethylquinoxaline (**3e**).* Purified by analytical TLC on silica gel with DCM/EA (50:1) as an eluent R_f = 0.48; white solid (74.0 mg, 77%). mp: 89−90 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.97 (d, J = 2.2 Hz, 1H), 7.91 (d, J = 8.9 Hz, 1H), 7.60 (dd, J = 8.9, 2.3 Hz, 1H), 2.72 (d, J = 1.8 Hz, 6H). ^{13}C{H} NMR (151 MHz, $CDCl_3$): δ 154.6, 153.8, 141.2, 139.6, 134.4, 129.8, 129.6, 127.4, 23.2, 23.1. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{10}H_{10}ClN_2$, 193.0527; found, 193.0528.

*6-Bromo-2,3-dimethylquinoxaline (**3f**).* Purified by analytical TLC on silica gel with DCM/EA (50:1) as an eluent R_f = 0.45; yellow solid (96.8 mg, 82%). mp: 82−83 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.15 (d, J = 2.1 Hz, 1H), 7.84 (d, J = 8.9 Hz, 1H), 7.73 (dd, J = 8.8, 2.1 Hz, 1H), 2.72 (d, J = 5.6 Hz, 6H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 154.5, 153.9, 141.8, 139.9, 132.2, 130.8, 129.7, 122.5, 23.2. HRMS

https://dx.doi.org/10.1021/acs.joc.0c02453
J. Org. Chem. XXXX, XXX, XXX−XXX

(ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{10}H_{10}BrN_2$, 237.0022; found, 237.0023.

*6-Methoxy-2,3-dimethylquinoxaline (**3g**).* Purified by analytical TLC on silica gel with DCM/EA (8:1) as an eluent R_f = 0.17; orange solid (77.5 mg, 82%). mp: 94−96 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.86 (d, J = 8.8 Hz, 1H), 7.33−7.29 (m, 2H), 3.94 (s, 3H), 2.70 (d, J = 5.2 Hz, 6H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 160.0, 153.4, 150.6, 142.5, 137.0, 129.3, 121.7, 106.2, 55.7, 23.1, 22.8. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{11}H_{13}N_2O$, 189.1022; found, 189.1023.

*2,3-Dimethyl-6-(4-methylpiperazin-1-yl)quinoxaline (**3h**).* Purified by column chromatography on alumina with EA as an eluent; yellow solid (119.5 mg, 93%). mp: 115−116 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.82 (d, J = 9.2 Hz, 1H), 7.43 (dd, J = 9.4, 1.7 Hz, 1H), 7.23 (d, J = 2.7 Hz, 1H), 3.38 (t, J = 5.1 Hz, 4H), 2.67 (d, J = 3.8 Hz, 6H), 2.62 (t, J = 5.1 Hz, 4H), 2.37 (s, 3H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 153.3, 151.3, 149.9, 142.5, 136.2, 128.6, 121.2, 109.6, 54.9, 48.7, 46.1, 23.1, 22.8. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{15}H_{21}N_4$, 257.1761; found, 257.1764.

*7-Bromo-2,3,5-trimethylquinoxaline (**3i**).* Purified by analytical TLC on silica gel with DCM/EA (60:1) as an eluent R_f = 0.19; brown solid (107.0 mg, 86%). mp: 63−65 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.98 (d, J = 2.0 Hz, 1H), 7.59 (d, J = 1.0 Hz, 1H), 2.73 (s, 3H), 2.71 (s, 6H). ^{13}C{H} NMR (151 MHz, $CDCl_3$): δ 153.9, 152.6, 141.8, 139.1, 138.7, 132.0, 128.5, 122.1, 23.3, 23.1, 16.9. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{11}H_{12}BrN_2$, 251.0178; found, 251.0178.

*2,3,6,7-Tetramethylquinoxaline (**3j**).* Purified by analytical TLC on silica gel with DCM/EA (50:1) as an eluent R_f = 0.38; yellow solid (87.5 mg, 94%). mp: 183−184 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.72 (s, 2H), 2.69 (s, 6H), 2.46 (s, 6H). ^{13}C{H} NMR (151 MHz, $CDCl_3$): δ 152.3, 140.0, 139.0, 127.5, 23.1, 20.1. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{12}H_{15}N_2$, 187.1230; found, 187.1230.

*6,7-Dichloro-2,3-dimethylquinoxaline (**3k**).* Purified by analytical TLC on silica gel with DCM/EA (50:1) as an eluent R_f = 0.58; brown solid (71.5 mg, 63%). mp: 189−190 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.09 (s, 2H), 2.72 (s, 6H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 154.9, 139.9, 133.1, 129.1, 23.2. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{10}H_9Cl_2N_2$, 227.0137; found, 227.0135.

*2,3-Diphenylquinoxaline (**4a**).* Purified by analytical TLC on silica gel with petroleum ether (PE)/DCM (1:1) as an eluent R_f = 0.40; white solid [135.1 mg, 96% yield from *o*-nitroanilines and 1,2-diphenylethane-1,2-diol; 28.0 mg, 99% yield from *o*-nitroanilines and 1-(4-bromophenyl)-2-hydroxyethan-1-one; 76.6 mg, 54% yield from 1,2-dinitrobenzene and 1,2-diphenylethane-1,2-diol]. mp: 119−120 °C. ^{1}H NMR (600 MHz, $CDCl_3$): δ 8.18 (dd, J = 6.3, 3.4 Hz, 2H), 7.78 (dd, J = 6.1, 3.2 Hz, 2H), 7.51 (d, J = 7.5 Hz, 4H), 7.38−7.32 (m, 6H). ^{13}C{H} NMR (151 MHz, $CDCl_3$): δ 153.50, 141.3, 139.1, 130.0, 129.9, 129.2, 128.8, 128.3. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{20}H_{15}N_2$, 283.1230; found, 283.1231.

*2,3-Di-p-tolylquinoxaline (**4b**).* Purified by analytical TLC on silica gel with PE/DCM (2:1) as an eluent R_f = 0.15; yellow solid (21.4 mg, 69% yield from 1,2-di-*p*-tolylethane-1,2-diol; 30.1 mg, 99% yield from 2-hydroxy-1,2-di-*p*-tolylethan-1-one). mp: 136−137 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.17−8.13 (m, 2H), 7.76−7.72 (m, 2H), 7.43 (d, J = 8.0 Hz, 4H), 7.15 (d, J = 8.0 Hz, 4H), 2.37 (s, 6H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 153.5, 141.2, 138.8, 136.4, 129.72, 129.65, 129.1, 129.0, 21.4. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{22}H_{19}N_2^+$, 311.1543; found, 311.1545.

*2,3-Bis(4-chlorophenyl)quinoxaline (**4c**).* Purified by analytical TLC on silica gel with PE/DCM (1:1) as an eluent R_f = 0.50; yellow solid (91.0 mg, 52%). mp: 176−177 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.18−8.14 (m, 2H), 7.82−7.77 (m, 2H), 7.49−7.45 (m, 4H), 7.36−7.33 (m, 4H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 151.9, 141.3, 137.3, 135.4, 131.2, 130.4, 129.2, 128.7. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{20}H_{13}Cl_2N_2$, 351.0450; found, 351.0452.

*2,3-Bis(4-bromophenyl)quinoxaline (**4d**).* Purified by analytical TLC on silica gel with PE/DCM (3:2) as an eluent R_f = 0.22; yellow solid (24.0 mg, 55%). mp: 186−187 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.17−8.14 (m, 2H), 7.82−7.78 (m, 2H), 7.51 (d, J = 8.5 Hz, 4H), 7.41 (d, J = 8.5 Hz, 4H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 151.9, 141.3, 137.7, 131.7, 131.4, 130.4, 129.2, 123.7. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{20}H_{13}Br_2N_2$, 438.9440; found, 438.9443.

*2,3-Bis(3-methoxyphenyl)quinoxaline (**4e**).* Purified by analytical TLC on silica gel with PE/DCM (1:3) as an eluent R_f = 0.19; yellow solid (133.6 mg, 98%). mp: 101−102 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.20−8.16 (m, 2H), 7.80−7.75 (m, 2H), 7.26−7.22 (m, 2H), 7.10−7.08 (m, 4H), 6.93−6.90 (m, 2H), 3.71 (s, 6H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 159.5, 153.3, 141.2, 140.3, 130.0, 129.3, 129.2, 122.4, 115.2, 114.8, 55.3. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{22}H_{19}N_2O_2$, 343.1441; found, 343.1444.

*1,2,3,4-Tetrahydrophenazine (**4f**).* Purified by analytical TLC on silica gel with DCM/EA (50:1) as an eluent R_f = 0.43; yellow solid (69.1 mg, 75% yield from *o*-nitroanilines; 30.7 mg, 33% yield from 1,2-dinitrobenzene). mp: 81−82 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.00−7.91 (m, 2H), 7.69−7.65 (m, 2H), 3.20−3.16 (m, 4H), 2.07−2.03 (m, 4H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 154.1, 141.1, 129.0, 128.3, 33.1, 22.8. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{12}H_{13}N_2$, 185.1073; found, 185.1072.

*2-Phenylquinoxaline (**4g**).* Purified by analytical TLC on silica gel with DCM as an eluent R_f = 0.55; yellow solid (74.2 mg, 72% yield from 1-phenylethane-1,2-diol; 12.6 mg, 61% yield from 2-hydroxy-1-phenylethan-1-one). mp: 71−72 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 9.34 (s, 1H), 8.22−8.12 (m, 4H), 7.82−7.73 (m, 2H), 7.60−7.51 (m, 3H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 151,5, 143.4, 142.3, 141.6, 136.8, 130.3, 130.2, 129.7, 129.6, 129.2, 127.6. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{14}H_{11}N_2$, 207.0917; found, 207.0918.

*2-(p-Tolyl)quinoxaline (**4h**).* Purified by analytical TLC on silica gel with PE/EA (10:1) as an eluent R_f = 0.33; yellow solid [15.4 mg, 70% yield from 1-(*p*-tolyl)ethane-1,2-diol; 11.1 mg, 50% yield from 2-hydroxy-1-(*p*-tolyl)ethan-1-one]. mp: 85−86 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 9.31 (s, 1H), 8.16−8.10 (m, 4H), 7.80−7.71 (m, 2H), 7.37 (d, J = 8.0 Hz, 2H), 2.46 (s, 3H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 151.9, 143.3, 142.4, 141.5, 140.5, 134.0, 129.9, 129.6, 129.3, 129.1, 127.4, 21.4. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{15}H_{13}N_2$, 221.1073; found, 221.1076.

*2-(4-Chlorophenyl)quinoxaline (**4i**).* Purified by analytical TLC on silica gel with PE/EA (10:1) as an eluent R_f = 0.31; brown solid [17.5 mg, 73% yield from 1-(4-chlorophenyl)ethane-1,2-diol; 13.2 mg, 55% yield from 1-(4-chlorophenyl)-2-hydroxyethan-1-one]. mp: 112−113 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 9.30 (s, 1H), 8.171−8.12 (m, 4H), 7.82−7.74 (m, 2H), 7.55−7.52 (m, 2H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 150.6, 142.9, 142.2, 141.7, 136.6, 135.2, 130.5, 129.8, 129.6, 129.4, 129.2, 128.8. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{14}H_{10}ClN_2$, 241.0527; found, 241.0530.

*2-(4-Bromophenyl)quinoxaline (**4j**).* Purified by analytical TLC on silica gel with PE/EA (10:1) as an eluent R_f = 0.26; yellow solid [20.2 mg, 71% yield from 1-(4-bromophenyl)ethane-1,2-diol; 15.6 mg, 55% yield from 1-(4-bromophenyl)-2-hydroxyethan-1-one]. mp: 132−133 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 9.31 (s, 1H), 8.19 (dd, J = 8.2, 1.7 Hz, 2H), 8.15 (d, J = 2.2 Hz, 1H), 8.05 (d, J = 8.9 Hz, 1H), 7.68 (dd, J = 8.9, 2.3 Hz, 1H), 7.60−7.52 (m, 3H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 150.6, 142.8, 142.2, 141.7, 135.6, 132.4, 129.8, 129.6, 129.2, 125.0. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{14}H_{10}BrN_2$, 285.0022; found, 285.0024.

*2-Methylquinoxaline (**4k**).* Purified by analytical TLC on silica gel with DCM/EA (50:1) as an eluent R_f = 0.51; yellow liquid (35.3 mg, 48% yield from propane-1,2-diol; 6.4 mg, 44% yield from 1-hydroxypropan-2-one). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.75 (s, 1H), 8.09−8.06 (m, 1H), 8.03−8.01 (m, 1H), 7.77−7.69 (m, 2H), 2.79 (s, 3H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 153.8, 146.0, 142.1, 141.0, 130.0, 129.2, 128.9, 128.7, 22.6. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_9H_9N_2$, 145.0760; found, 145.0759.

*2-Ethylquinoxaline (**4l**).* Purified by analytical TLC on silica gel with DCM/EA (50:1) as an eluent R_f = 0.39; yellow liquid (41.8 mg, 53%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.77 (s, 1H), 8.09−8.04 (m, 2H), 7.77−7.69 (m, 2H), 3.07 (q, J = 7.6 Hz, 2H), 1.45 (t, J = 7.6 Hz, 3H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 158.5, 145.6, 142.2, 141.3, 129.9, 129.2, 128.91, 128.88, 29.6, 13.4. HRMS (ESI$^+$, MeOH) m/z: $[M + H]^+$ calcd for $C_{10}H_{11}N_2$, 159.0917; found, 159.0923.

https://dx.doi.org/10.1021/acs.joc.0c02453
J. Org. Chem. XXXX, XXX, XXX−XXX

*2-Propylquinoxaline (**4m**).* Purified by analytical TLC on silica gel with DCM/EA (50:1) as an eluent R_f = 0.74; yellow liquid (48.2 mg, 55%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.75 (s, 1H), 8.09−8.03 (m, 2H), 7.77−7.69 (m, 2H), 3.00 (t, J = 7.7 Hz, 2H), 1.94−1.83 (m, 2H), 1.05 (t, J = 7.4 Hz, 3H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 157.5, 145.9, 142.2, 141.2, 129.9, 129.2, 128.91, 128.88, 38.4, 22.8, 13.9. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{11}H_{13}N_2$, 173.1073; found, 173.1075.

*2-Butylquinoxaline (**4n**).* Purified by analytical TLC on silica gel with PE/EA (10:1) as an eluent R_f = 0.44; yellow liquid (75.6 mg, 81%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.73 (s, 1H), 8.07−8.02 (m, 2H), 7.74−7.66 (m, 2H), 3.00 (t, J = 7.8 Hz, 2H), 1.86−1.79 (m, 2H), 1.50−1.40 (m, 2H), 0.96 (t, J = 7.4 Hz, 3H). ^{13}C{H} NMR (151 MHz, $CDCl_3$): δ 157.7, 145.8, 142.2, 141.2, 129.9, 129.2, 128.9, 36.2, 31.6, 22.6, 13.9. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{12}H_{15}N_2$, 187.1230; found, 187.1231.

*2-Hexylquinoxaline (**4o**).* Purified by analytical TLC on silica gel with PE/EA (10:1) as an eluent R_f = 0.48; yellow liquid (87.8 mg, 82%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.73 (s, 1H), 8.08−8.02 (m, 2H), 7.75−7.67 (m, 2H), 3.00 (t, J = 7.7 Hz, 2H), 1.88−1.80 (m, 2H), 1.44−1.39 (m, 2H), 1.37−1.28 (m, 4H), 1.88 (t, J = 7.2 Hz, 3H). ^{13}C{H} NMR (151 MHz, $CDCl_3$): δ 157.7, 145.8, 142.2, 141.2, 129.9, 129.2, 128.9, 36.5, 31.6, 29.5, 22.5, 14.0. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{14}H_{19}N_2$, 215.1543; found, 215.1546.

*2-(Naphthalen-2-yl)quinoxaline (**4p**).* Purified by analytical TLC on silica gel with PE/EA (10:1) as an eluent R_f = 0.30; yellow solid (20.5 mg, 80%). mp: 126−127 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 9.48 (s, 1H), 8.66 (s, 1H), 8.36 (dd, J = 8.6, 1.8 Hz, 1H), 8.21−8.19 (m, 1H), 8.16−8.13 (m, 1H), 8.04−8.00 (m, 2H), 7.92−7.90 (m, 1H), 7.83−7.73 (m, 2H), 7.59−7.54 (m, 2H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 151.7, 143.5, 142.4, 141.6, 134.2, 134.1, 133.4, 130.4, 129.7, 129.6, 129.2, 129.1, 128.9, 127.8, 127.5, 127.3, 126.7, 124.5. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{18}H_{13}N_2$, 257.1073; found, 257.1076.

*6-Methyl-2,3-diphenylquinoxaline (**4q**).* Purified by analytical TLC on silica gel with PE/DCM (1:1) as an eluent R_f = 0.48; white solid (136.6 mg, 92%). mp: 111−112 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.06 (d, J = 8.5 Hz, 1H), 7.95 (s, 1H), 7.61(dd, J = 8.6, 1.8 Hz, 1H), 7.52−7.49 (m, 4H), 7.36−7.30 (m, 6H), 2.62 (s, 3H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 153.3, 152.6, 141.3, 140.5, 139.7, 139.2, 132.3, 129.9, 129.8, 128.73, 128.70, 128.6, 128.2, 128.0, 21.9. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{21}H_{17}N_2$, 297.1387; found, 297.1387.

*6-Chloro-2,3-diphenylquinoxaline (**4r**).* Purified by analytical TLC on silica gel with PE/DCM (2:1) as an eluent R_f = 0.18; white solid (145.7 mg, 92% yield from 4-chloro-2-nitroaniline; 153.6 mg, 97% yield from 5-chloro-2-nitroaniline). mp: 110−111 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.15 (d, J = 2.2 Hz, 1H), 8.08 (d, J = 9.2 Hz, 1H), 7.68 (dd, J = 8.9, 2.3 Hz, 1H), 7.51−7.49 (m, 4H), 7.38−7.30 (m, 6H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 154.3, 153.6, 141.5, 139.7, 138.8, 138.7, 135.7, 131.0, 130.5, 129.9, 129.8, 129.1, 129.0, 128.35, 128.34, 128.1. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{20}H_{14}ClN_2$, 317.0840; found, 317.0840.

*6,7-Dimethyl-2,3-diphenylquinoxaline (**4s**).* Purified by analytical TLC on silica gel with PE/DCM (1:1) as an eluent R_f = 0.38; white solid (152.0 mg, 98%). mp: 176−177 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.92 (s, 2H), 7.51−7.49 (m, 4H), 7.35−7.29 (m, 6H), 2.52 (s, 6H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 152.5, 140.5, 140.2, 139.4, 129.9, 128.5, 128.23, 128.20, 20.4. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{22}H_{19}N_2$, 311.1543; found, 311.1541.

*6,7-Dichloro-2,3-diphenylquinoxaline (**4t**).* Purified by analytical TLC on silica gel with PE/DCM (2:1) as an eluent R_f = 0.28; white solid (140.2 mg, 80%). mp: 138−139 °C. ^{1}H NMR (600 MHz, $CDCl_3$): δ 8.29 (s, 2H), 7.50 (d, J = 7.5 Hz, 4H), 7.40−7.33 (m, 6H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 154.5, 140.0, 138.4, 134.4, 129.8, 129.3, 128.4. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{20}H_{13}Cl_2N_2$, 351.0450; found, 351.0452.

*7-Methyl-1,2,3,4-tetrahydrophenazine (**4u**).* Purified by analytical TLC on silica gel with DCM/EA (50:1) as an eluent R_f = 0.35; yellow solid (79.2 mg, 80%). mp: 80−81 °C. ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.85 (d, J = 8.4 Hz, 1H), 7.73 (s, 1H), 7.49 (d, J = 8.4 Hz, 1H), 3.14 (m, 4H), 2.56 (s, 3H), 2.03 (m, 4H). ^{13}C{H} NMR (151 MHz, $CDCl_3$): δ 154.0, 153.1, 141.3, 139.7, 139.2, 131.2, 127.9, 127.3, 33.2, 33.1, 22.88, 22.87, 21.8. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{13}H_{15}N_2$, 199.1230; found, 199.1232.

*7-Chloro-1,2,3,4-tetrahydrophenazine (**4v**).* Purified by analytical TLC on silica gel with DCM/EA (50:1) as an eluent R_f = 0.50; brown solid (63.6 mg, 58% yield from 4-chloro-2-nitroaniline; 75.0 mg, 69% yield from 5-chloro-2-nitroaniline). mp: 91−92 °C. ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.96 (s, 1H), 7.89 (d, J = 8.7 Hz, 1H), 7.60 (d, J = 8.7 Hz, 1H), 3.15 (m, 4H), 2.04 (m, 4H). ^{13}C{H} NMR (151 MHz, $CDCl_3$): δ 155.3, 154.5, 141.5, 139.7, 134.5, 129.9, 129.6, 127.4, 33.21, 33.16, 22.70, 22.68. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{12}H_{12}ClN_2$, 219.0684; found, 219.0683.

*7,8-Dimethyl-1,2,3,4-tetrahydrophenazine (**4w**).* Purified by analytical TLC on silica gel with DCM/EA (50:1) as an eluent R_f = 0.40; yellow solid (74.2 mg, 70%). mp: 143−145 °C. ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.70 (s, 2H), 3.13 (m, 4H), 2.46 (s, 6H), 2.02 (m, 4H). ^{13}C{H} NMR (151 MHz, $CDCl_3$): δ 153.0, 140.2, 139.2, 127.5, 33.1, 22.9, 20.3. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{14}H_{17}N_2$, 213.1386; found, 213.1386.

*8-Bromo-6-methyl-1,2,3,4-tetrahydrophenazine (**4x**).* Purified by analytical TLC on silica gel with PE/DCM (1:1) as an eluent R_f = 0.33; yellow solid (70.7 mg, 51%). mp: 63−65 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.98 (d, J = 1.8 Hz, 1H), 7.59 (d, J = 1.1 Hz, 1H), 3.15−3.12 (m, 4H), 2.73 (s, 3H), 2.05−2.01 (m, 4H). ^{13}C{H} NMR (151 MHz, $CDCl_3$): δ 154.6, 153.4, 141.9, 139.3, 138.7, 132.1, 128.5, 122.2, 33.4, 33.1, 22.8, 17.0. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{13}H_{14}BrN_2$, 277.0335; found, 277.0340.

*6,7-Dimethyl-2-phenylquinoxaline (**4y**).* Purified by analytical TLC on silica gel with DCM/EA (50:1) as an eluent R_f = 0.64; white solid (93.5 mg, 80%). mp: 128−130 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 9.22 (s, 1H), 8.18−8.16 (m, 2H), 7.91 (s, 1H), 7.86 (s, 1H), 7.58−7.48 (m, 3H), 2.51 (s, 6H). ^{13}C{H} NMR (151 MHz, $CDCl_3$): δ 151.0, 142.4, 141.3, 140.8, 140.6, 140.1, 137.2, 129.8, 129.1, 128.7, 128.2, 127.4, 20.4, 20.3. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{16}H_{15}N_2$, 235.1230; found, 235.1230.

*6,7-Dichloro-2-phenylquinoxaline (**4z**).* Purified by analytical TLC on silica gel with PE/EA (15:1) as an eluent R_f = 0.53; yellow solid (63.0 mg, 46%). mp: 155−157 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 9.32 (s, 1H), 8.28 (s, 1H), 8.24 (s, 1H), 8.20−8.18 (m, 2H), 7.61−7.55 (m, 3H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 152.7, 144.3, 141.1, 140.3, 136.0, 134.9, 134.0, 130.9, 130.2, 129.8, 129.3, 127.6. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{14}H_9Cl_2N_2$, 275.0137; found, 275.0142.

*2,3-Bis(4-methoxyphenyl)quinoxaline (**4aa**).* Purified by analytical TLC on silica gel with PE/DCM (1:3) as an eluent R_f = 0.21; yellow solid (34.0 mg, 99% yield from *o*-nitroanilines; 89.2 mg, 52% yield from 1,2-dinitrobenzene). mp: 143 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.14−8.10 (m, 2H), 7.73−7.69 (m, 2H), 7.51−7.48 (m, 4H), 6.89−6.85 (m, 4H), 3.82 (s, 6H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 160.2, 153.0, 141.1, 131.8, 131.3, 129.5, 129.0, 113.8, 55.3. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{22}H_{19}N_2O_2$, 343.1441; found, 343.1444.

*2,3-Di(furan-2-yl)quinoxaline (**4ab**).* Purified by analytical TLC on silica gel with PE/DCM (1:3) as an eluent R_f = 0.42; brown solid (25.9 mg, 99%). mp: 122−123 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.16−8.12 (m, 2H), 7.77−7.32 (m, 2H), 7.63 (dd, J = 1.7, 0.67 Hz, 2H), 6.66 (dd, J = 3.5, 0.52 Hz, 2H), 6.57 (dd, J = 3.5, 1.7 Hz, 2H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 150.8, 144.2, 142.7, 140.6, 130.4, 129.1, 113.0, 111.9. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{16}H_{11}N_2O_2$, 263.0815; found, 263.0818.

*2,3-Bis(4-methoxyphenyl)-6-methylquinoxaline (**4ac**).* Purified by analytical TLC on silica gel with PE/DCM (1:3) as an eluent R_f = 0.23; yellow solid (31.6 mg, 88%). mp: 118−119 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.01 (d, J = 8.5 Hz, 1H), 7.90 (s, 1H), 7.55 (dd, J = 6.8, 1.8 Hz, 1H), 7.50−7.46 (m, 4H), 6.88−6.85 (m, 4H), 3.82 (s, 6H), 2.59 (s, 3H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 160.1, 160.0, 152.9, 152.2, 141.1, 140.0, 139.5, 131.91, 131.86, 131.2, 128.5, 127.9, 113.8, 113.7,

https://dx.doi.org/10.1021/acs.joc.0c02453
J. Org. Chem. XXXX, XXX, XXX−XXX

55.3, 21.9. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{23}H_{21}N_2O_2$, 357.1598; found, 357.1062.

*6-Chloro-2,3-bis(4-methoxyphenyl)quinoxaline (**4ad**).* Purified by analytical TLC on silica gel with PE/DCM (1:3) as an eluent R_f = 0.38; yellow solid (33.5 mg, 89% yield from 4-chloro-2-nitroaniline; 37.2 mg, 98% yield from 5-chloro-2-nitroaniline). mp: 147−148 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.10 (d, J = 2.3 Hz, 1H), 8.03 (d, J = 8.5 Hz, 1H), 7.64 (dd, J = 8.5, 2.3 Hz, 1H), 7.50−7.46 (m, 4H), 6.89−6.85 (m, 4H), 3.83 (s, 6H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 160.4, 160.3, 153.8, 153.2, 141.3, 139.5, 135.1, 131.38, 131.30, 131.28, 131.23, 130.5, 130.2, 127.9, 113.84, 113.83, 55.3. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{22}H_{18}ClN_2O_2$, 377.1051; found, 377.1054.

*6-Methoxy-2,3-bis(4-methoxyphenyl)quinoxaline (**4ae**).* Purified by analytical TLC on silica gel with PE/DCM (1:3) as an eluent R_f = 0.10; yellow solid (36.6 mg, 98% yield). mp: 126−127 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.01 (d, J = 9.1 Hz, 1H), 7.49−7.42 (m, 5H), 7.37 (dd, J = 9.1, 2.8 Hz, 1H), 6.89−6.84 (m, 4H), 3.97 (s, 3H), 3.82 (d, J = 1.4 Hz, 6H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 160.9, 160.1, 159.9, 152.9, 150.6, 142.6, 137.2, 131.92, 131.90, 131.2, 131.1, 130.0, 122.8, 113.8, 106.4, 55.8, 55.3. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{23}H_{21}N_2O_3$, 373.1547; found, 373.1550.

*6,7-Dichloro-2,3-bis(4-methoxyphenyl)quinoxaline (**4af**).* Purified by analytical TLC on silica gel with PE/DCM (1:3) as an eluent R_f = 0.54; yellow solid (36.9 mg, 90%). mp: 156−157 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.21 (s, 2H), 7.50−7.46 (m, 4H), 6.89−6.85 (m, 4H), 3.83 (s, 6H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 160.6, 154.0, 139.8, 133.8, 131.3, 131.0, 129.6, 113.9, 55.3. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{22}H_{17}Cl_2N_2O_2$, 411.0662; found, 411.0661.

*6-Chloro-2,3-di(furan-2-yl)quinoxaline (**4ag**).* Purified by analytical TLC on silica gel with PE/EA (10:1) as an eluent R_f = 0.33; brown solid (27.5 mg, 93% yield from 4-chloro-2-nitroaniline; 23.9 mg, 81% yield from 5-chloro-2-nitroaniline). mp: 108−109 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.12 (d, J = 2.2 Hz, 1H), 8.05 (d, J = 9.0 Hz, 1H), 7.67 (dd, J = 9.0, 2.2 Hz, 1H), 7.63−7.62 (m, 2H) 6.71−6.70 (m, 2H), 6.57 (dd, J = 3.5, 1.7 Hz, 2H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 150.6, 150.5, 144.6, 144.4, 143.3, 142.6, 140.9, 139.1, 136.2, 131.3, 130.3, 128.0, 113.7, 113.4, 112.1, 112.0. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{16}H_{10}ClN_2O_2$, 297.0425; found, 297.0428.

*2,3-Di(furan-2-yl)-6-methoxyquinoxaline (**4ah**).* Purified by analytical TLC on silica gel with PE/EA (10:1) as an eluent R_f = 0.15; brown solid (22.9 mg, 78%). mp: 105−106 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.01 (d, J = 9.2 Hz, 1H), 7.63−7.60 (m, 2H), 7.45 (d, J = 2.7 Hz, 1H), 7.39 (dd, J = 9.2, 2.7 Hz, 1H), 6.66 (dd, J = 3.4, 0.62 Hz, 1H), 6.56 (dd, J = 3.4, 1.8 Hz, 1H), 6.54 (d, J = 1.2 Hz, 2H), 3.97 (s, 3H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 161.4, 151.0, 150.8, 144.2, 143.7, 142.7, 142.4, 140.2, 136.7, 130.1, 123.9, 113.0, 112.0, 111.9, 111.8 106.5, 55.9. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{17}H_{13}N_2O_3$, 293.0921; found, 293.0924.

*6,7-Dichloro-2,3-di(furan-2-yl)quinoxaline (**4ai**).* Purified by analytical TLC on silica gel with PE/EA (10:1) as an eluent R_f = 0.37; brown solid (24.8 mg, 75%). mp: 136−138 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.23 (s, 2H), 7.63 (dd, J = 1.7, 0.62 Hz, 2H), 6.73 (dd, J = 3.5, 0.63 Hz, 2H), 6.58 (dd, J = 3.5, 1.7 Hz, 2H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 150.3, 144.7, 143.3, 139.3, 134.8, 129.6, 113.9, 112.1. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{16}H_9Cl_2N_2O_2$, 331.0036; found, 331.0039.

Procedure for the Preparation of 3-Methylquinoxaline-2-carbaldehyde 7. To a mixture solution of dioxane/H_2O (5:1, 12 mL) were added **3a** (158.2 mg, 1.0 mmol) and selenium dioxide (111.9 mg, 1.3 mmol). After refluxing in a preheated oil bath for 12 h, water (8 mL) was added and extracted with ethyl acetate (3 × 10 mL). The combined organic layer was dried over anhydrous $MgSO_4$ and concentrated under vacuum. The residue was purified by preparative TLC on silica gel plates using PE/EA (10:1) as the eluent to give product **7** in 67% yield. R_f = 0.37; yellow solid (116.2 mg, 67%). mp: 136−138 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 10.32 (s, 1H), 8.20 (d, J = 8.3 Hz, 1H), 8.09 (d, J = 8.5 Hz, 1H), 7.92−7.88 (m, 1H), 7.81 (t, J = 7.5 Hz, 1H), 3.05 (s, 3H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 194.0, 153.6, 145.2, 142.8, 140.8, 133.0, 130.00, 129.98, 128.6, 23.3. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{10}H_9N_2O$, 173.0709; found, 173.0708.

Procedure for the Preparation of 2,3-Dimethyl-1,2,3,4-tetrahydroquinoxaline 8. To a Schlenk tube were added **3a** (39.5 mg, 0.25 mmol) and AgOTf (3.2 mg, 0.0125 mmol) in deionized water (1.0 mL). $PhSiH_3$ (108.0 mg, 1.0 mmol) was added dropwise using a syringe over 1 min under air. The reaction mixture was stirred at room temperature for 30 min, diluted with deionized water (5.0 mL), and extracted with ethyl acetate (3 × 5 mL). After removal of the organic solvent, the residue was purified by preparative TLC on silica gel plates using PE/EA (10:1) as the eluent to give product **8** in 88% yield. R_f = 0.16; yellow solid (35.8 mg, 88%). mp: 104−106 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.59−6.56 (m, 2H), 6.51−6.48 (m, 2H), 3.48 (q, J = 5.7 Hz, 2H), 3.36 (s, 2H), 1.11 (d, J = 6.4 Hz, 6H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 132.6, 118.6, 114.5, 49.1, 17.2. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{10}H_{15}N_2$, 163.1230; found, 163.1227.

Procedure for the Preparation of 2,3-Diphenethylquinoxaline 9. To an oven-dried 35 mL Ace pressure tube were added **3a** (39.5 mg, 0.25 mmol), benzyl alcohol (108.1 mg, 1.0 mmol), KO^{t}Bu (14.0 mg, 0.125 mmol), $NiBr_2$ (5.5 mg, 0.025 mmol), and 1,10-phenanthroline (22.5 mg, 0.13 mmol) in toluene (2.0 mL) under Ar. The sealed tube was capped and taken out of a glovebox. After stirring in a preheated oil bath at 140 °C for 12 h, the reaction mixture was cooled down to room temperature and directly concentrated under vacuum. The residue was purified by preparative TLC on silica gel plates using PE/EA (5:1) as the eluent to give product **9** in 96% yield. R_f = 0.63; yellow solid (81.6 mg, 96%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.07−8.03 (m, 2H), 7.71−7.67 (m, 2H), 7.30−7.26 (m, 4H), 7.22−7.18 (m, 6H), 3.26−3.21 (m, 4H), 3.17−3.13 (m, 4H). ^{13}C{H} NMR (101 MHz, $CDCl_3$): δ 155.4, 141.5, 141.0, 129.0, 128.6, 128.52, 128.51, 126.2, 37.0, 34.3. HRMS (ESI$^+$, MeOH) m/z: [M + H]$^+$ calcd for $C_{24}H_{23}N_2$, 339.1856; found, 339.1858.

Gram-Scale Synthesis. To a 250 mL round-bottom flask equipped with a Dean−Stark apparatus were added **1a** (13.8 g, 100 mmol), **2a** (36.0 g, 400 mmol), and NaOH (2.00 g, 50 mol %) in toluene (100 mL) under Ar. The mixture was refluxed in a preheated oil bath for 4 h and cooled down to ambient temperature afterward. After the removal of organic solvent, water (100 mL) was added and extracted with ethyl acetate (3 × 150 mL). The combined organic layer was dried over anhydrous $MgSO_4$ and concentrated under vacuum. The residue was purified through a silica gel column using DCM as the eluent to give pure sulfonylated product **3a** in 87% (13.7 g) isolated yield.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.joc.0c02453.

Optimization of reaction conditions, ICP analysis, mechanistic studies, and NMR spectra of compounds (PDF)

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https://dx.doi.org/10.1021/acs.joc.0c02453
J. Org. Chem. XXXX, XXX, XXX−XXX

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

Financial support from the National Natural Science Foundation of China (grant nos. 21672192, 21803059, and U1904212) is gratefully appreciated.

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