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Synthesis of Indeno[1′,2′:4,5]imidazo[1,2-*a*]pyridin-11-ones and Chromeno[4′,3′:4,5]imidazo[1,2-*a*]pyridin-6-ones through Palladium-Catalyzed Cascade Reactions of 2-(2-Bromophenyl)imidazo[1,2-*a*]pyridines

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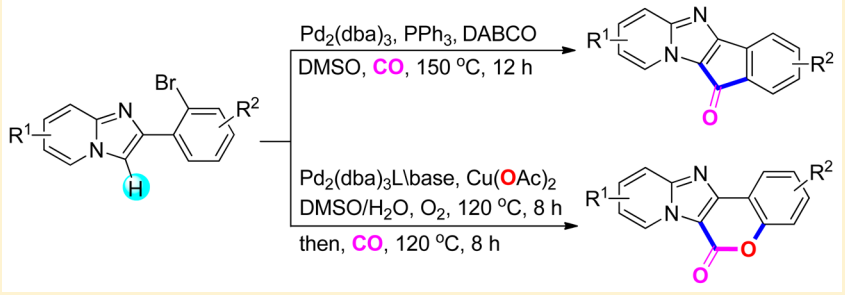
Supporting Information



ABSTRACT: A novel and efficient synthesis of 11*H*-indeno[1′,2′:4,5]imidazo[1,2-*a*]pyridin-11-one, a hybrid structure of indenone with imidazo[1,2-*a*]pyridine, from the reaction of 2-(2-bromophenyl)imidazo[1,2-*a*]pyridine with carbon monoxide through palladium-catalyzed CO insertion and C−H bond activation, has been developed. Intriguingly, under similar conditions but in the presence of $Cu(OAc)_2$, the reaction selectively afforded 6*H*-chromeno[4′,3′:4,5]imidazo[1,2-*a*]pyridin-6-one, a hybrid structure of chromenone with imidazo[1,2-*a*]pyridine, via a more sophisticated cascade process including acetoxylation, deacetylation, CO insertion, and C−H bond activation.

INTRODUCTION

Indenone derivatives have been well-established as an important class of carbocyclic scaffolds commonly encountered in natural products, pharmaceuticals, and functional materials.[1−3] In particular, many indenones fused with a N- or O-heterocyclic unit are privileged structures with significant biological activities. For example, 5*H*-indeno[1,2-*c*]pyridazin-5-ones are effective type B MAO inhibitors.[4a] Euplectin, a natural product featuring an indenone moiety fused onto 5-hydroxychromone, exhibits cytotoxicity against the growth of murine P-815 mastocytoma cells.[4b] Indenoisoquinolines, bearing a hybrid structure of indenone with isoquinoline, are potent topoisomerase inhibitors.[4c,d] Due to their importance, a number of efficient methods for the preparation of indenone and its derivatives have been developed.[5] Classically, indenones were synthesized through transition-metal-catalyzed annulations of *ortho*-functionalized benzaldehydes, esters, amides, nitriles, benzyl halides, or benzyl alcohols.[6] In recent years, synthesis of indenones via direct annulations of benzaldehydes, nitrones, or azomethines with alkynes is rapidly prevailing by taking advantage of the powerful C−H bond activation technology.[7] Moreover, indenones could also be prepared through cyclocarbonylation of arynes, tandem [3,3]propargyl ester rearrangement of propargyl pivolates followed by Michael addition, and Selectfluor-mediated annulation of 1,6-enynes.[8]

Meanwhile, the imidazo[1,2-*a*]pyridine (IP) framework is attracting considerable attention as it serves as a backbone structure of numerous antiviral, antimicrobial, antitumor agents, and neuroactive pharmaceuticals such as necopidem, saripidem, and zolpidem.[9−11] As a continuation of our recent interest in searching new synthetic methods for the preparation of IPs and other heterocycles,[12] we have developed an efficient preparation of 11*H*-indeno[1′,2′:4,5]imidazo[1,2-*a*]pyridin-11-one (IIP), a hybrid structure of indenone with IP, and a novel synthetic approach toward 6*H*-chromeno[4′,3′:4,5]imidazo[1,2-*a*]-pyridin-6-one (CIP), a hybrid structure of chromenone with IP. Herein, we wish to report our results in this regard.

RESULTS AND DISCUSSION

Our study was initiated by treating 2-(2-bromophenyl)imidazo-[1,2-*a*]pyridine (BPIP, **1a**) with CO (1 atm) in the presence of $Pd(OAc)_2$, *n*-butyl di(1-adamantyl)phosphine (BDAP), and 1,4-diazabicyclo[2.2.2]octane (DABCO) in DMSO at 120 °C for 12

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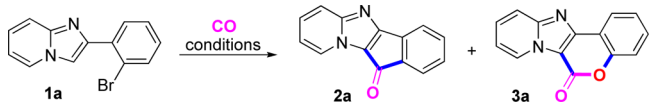
Table 1. Optimization Studies on the Synthesis of 2a[a]



entry	catalyst	cocatalyst	ligand	base	solvent	T (°C)	yield (%)[b] 2a	yield (%)[b] 3a
1	$Pd(OAc)_2$		BDAP	DABCO	DMSO	120	20	nd
2	$Pd(OAc)_2$		PPh_3	DABCO	DMSO	120	33	nd
3	$Pd(OAc)_2$		TCHP	DABCO	DMSO	120	29	nd
4	$Pd(OAc)_2$		TFP	DABCO	DMSO	120	21	nd
5	$Pd(OAc)_2$		TBPF	DABCO	DMSO	120	20	nd
6	$Pd(OAc)_2$		S-Phos	DABCO	DMSO	120	22	nd
7	$Pd(OAc)_2$		X-Phos	DABCO	DMSO	120	15	nd
8	$PdCl_2$		PPh_3	DABCO	DMSO	120	38	nd
9	$Pd_2(dba)_3$		PPh_3	DABCO	DMSO	120	52	nd
10	$Pd(PPh_3)_2Cl_2$		PPh_3	DABCO	DMSO	120	20	nd
11	$Pd(PPh_3)_4$		PPh_3	DABCO	DMSO	120	15	nd
12	$Pd(CF_3CO_2)_2$		PPh_3	DABCO	DMSO	120	41	nd
13	$Pd_2(dba)_3$		PPh_3	Na_2CO_3	DMSO	120	35	nd
14	$Pd_2(dba)_3$		PPh_3	K_2CO_3	DMSO	120	27	nd
15	$Pd_2(dba)_3$		PPh_3	Cs_2CO_3	DMSO	120	12	nd
16	$Pd_2(dba)_3$		PPh_3	DBU	DMSO	120	44	nd
17	$Pd_2(dba)_3$		PPh_3	Et_3N	DMSO	120	trace	nd
18	$Pd_2(dba)_3$		PPh_3	DABCO	DMF	120	19	nd
19	$Pd_2(dba)_3$		PPh_3	DABCO	NMP	120	32	nd
20	$Pd_2(dba)_3$		PPh_3	DABCO	toluene	120	trace	nd
21	$Pd_2(dba)_3$		PPh_3	DABCO	DMSO	130	57	nd
22	$Pd_2(dba)_3$		PPh_3	DABCO	DMSO	150	68	nd
23	$Pd_2(dba)_3$		PPh_3	DABCO	DMSO	160	62	nd
24	$Pd_2(dba)_3$			DABCO	DMSO	150	9	nd
25	$Pd_2(dba)_3$		PPh_3		DMSO	150	nd	nd
26			PPh_3	DABCO	DMSO	150	nd	nd
27	$Pd_2(dba)_3$	CuI	PPh_3	DABCO	DMSO	150	56	nd
28	$Pd_2(dba)_3$	$Cu(OAc)_2$	PPh_3	DABCO	DMSO	150	6	18

[a]Reaction conditions: **1a** (0.5 mmol), catalyst (0.05 mmol), ligand (0.075 mmol), cocatalyst (0.25 mmol), base (1.5 mmol), solvent (2 mL), CO (1 atm), 12 h. [b]Isolated yield; nd = not detected.

h. From this reaction, the expected IIP **2a** was obtained in a yield of 20% (Table 1, entry 1). To improve the efficiency, different ligands, including PPh_3, tricyclohexylphosphine (TCHP), tris(2-furanyl)phosphine (TFP), tri-(*tert*-butyl)phosphonium tetrafluoroborate (TBPF), 2-dicyclohexylphosphino-2′,6′-dimethoxybiphenyl (S-Phos), and 2-dicyclohexylphosphino-2′,4′,6′-triisopropylbiphenyl (X-Phos), were then used (entries 2−7). Among them, PPh_3 gave the best result. In following studies, other Pd catalysts such as $PdCl_2$, $Pd_2(dba)_3$, $Pd(PPh_3)_2Cl_2$, $Pd(PPh_3)_4$, and $Pd(CF_3CO_2)_2$ were also tried (entries 8−12). Of these catalysts, $Pd_2(dba)_3$ was the most effective (entry 9). Next, the effect of several inorganic and organic bases including Na_2CO_3, K_2CO_3, Cs_2CO_3, DBU, and Et_3N was tested, but none of them gave a better result than DABCO (entries 13−17 vs entry 9). When DMF, NMP, or toluene was used to replace DMSO as the reaction medium, the yield of **4a** decreased (entries 18−20 vs entry 9). In further optimization, we were pleased to find that increasing the reaction temperature from 120 to 130 °C or 150 °C could improve the yield of **2a** from 52 to 57 or 68% (entries 21 and 22 vs entry 9). Further increase in the temperature did not result in higher yield (entry 23). In the absence of ligand, the yield of **2a** decreased dramatically (entry 24). In the absence of a Pd catalyst or base, **2a** could not be detected (entries 25 and 26). Further studies showed that using CuI as a possible cocatalyst did not gave a higher yield of **2a** (entry 27). Surprisingly, when $Cu(OAc)_2$ was tried as a cocatalyst, the formation of **2a** was significantly suppressed, and the reaction afforded CIP **3a** in a yield of 18% (entry 28).

With the optimized reaction conditions in hand (Table 1, entry 22), the scope and generality for the synthesis of IIPs (**2**) was explored, and the results are listed in Table 2. First, a series of BPIP substrates bearing various substituents on the 2-phenyl unit were tried. It turned out that either electron-donating or electron-withdrawing group(s) substituted BPIPs (**1**) took part in this reaction smoothly to give the corresponding products **2b−2i** in moderate yields. No obvious electronic effect was observed. Second, BPIPs (**1**) bearing different substituents on the IP scaffold were tested. The results showed that BPIPs (**1**) having a methyl, chloro, fluoro, trifluoromethyl, or cyano group on the IP moiety were all suitable for this cascade process to give products **2j−2p**. While the reactions did not show obvious steric effect with BPIPs bearing a substituent attached on the 6-, 7-, or 8-position of the IP unit, the BPIP derivative bearing a methyl group on the 5-position of the IP scaffold failed to give the expected product. Third, substrates having substituents attached on both the 2-phenyl and the IP units took part in this reaction smoothly to afford **2q−2w** in moderate yields.

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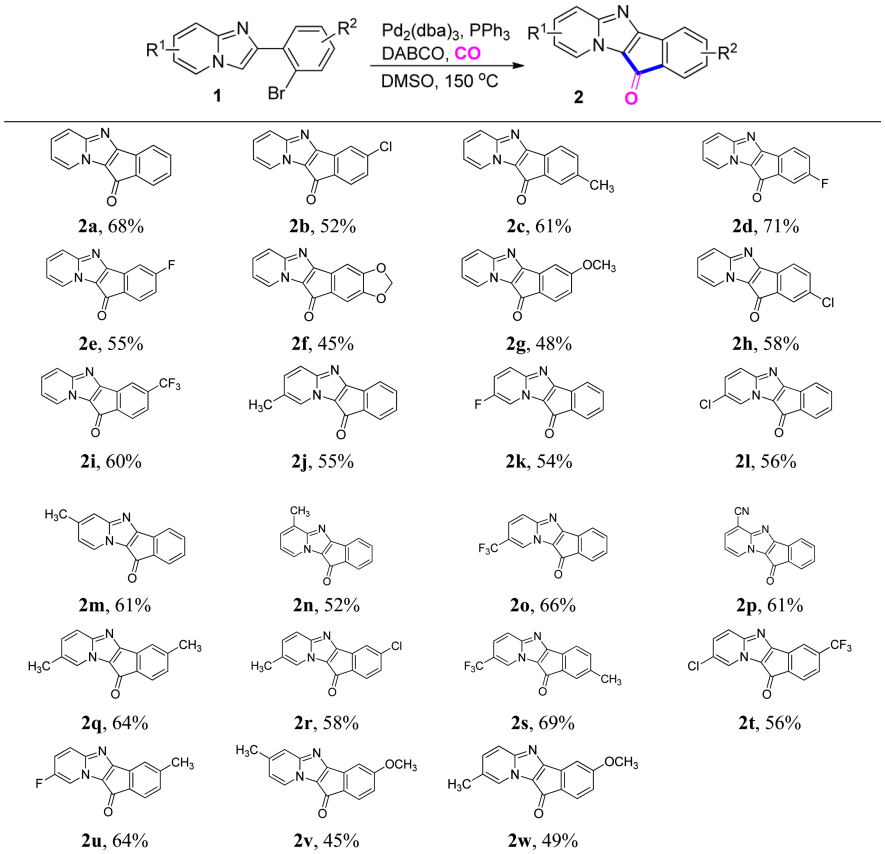
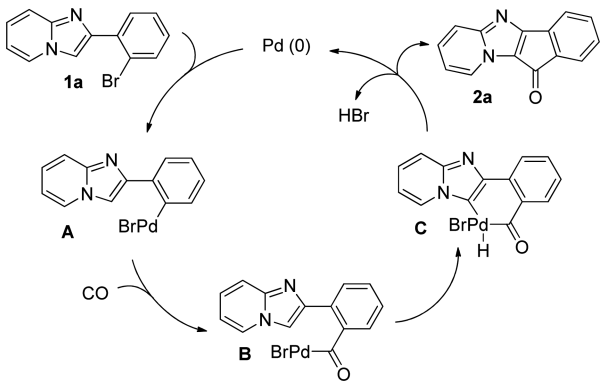
Table 2. Studies on the Generality for the Synthesis of 2[a,b]



[a]Reaction conditions: **1** (0.5 mmol), $Pd_2(dba)_3$ (0.05 mmol), PPh_3 (0.075 mmol), DABCO (1.5 mmol), DMSO (2 mL), CO (1 atm), 150 °C, 12 h. [b]Isolated yield.

Based on the above results and previous reports,[13] a plausible mechanism for the formation of **2a** is depicted in Scheme 1.

Scheme 1. Plausible Reaction Pathway for the Formation of 2a from 1a



Initially, oxidative addition of Pd(0) into the C−Br bond in **1a** forms intermediate **A**, which then undergoes a CO insertion to afford an acylpalladium complex **B**. The following oxidative addition of the neighboring C−H bond in the IP unit to the acylpalladium complex generates intermediate **C**. Finally, reductive elimination occurs with **C** to afford **2a** and regenerate the Pd(0) catalyst.

Having established an efficient synthesis of 11*H*-indeno[1′,2′:4,5]imidazo[1,2-*a*]pyridin-11-ones (**2**), we moved our attention back to 6*H*-chromeno[4′,3′:4,5]imidazo[1,2-*a*]-pyridin-6-one (**3a**), a chromenone−imidazopyridine hybrid obtained as an unexpected byproduct in the course of optimizing the reaction conditions for the preparation of **2a** (see Table 1, entry 28). It is well-known that chromenone constitutes the central core of a wide variety of naturally occurring and man-made compounds exhibiting extraordinary biological and pharmaceutical properties.[14] It is thus reasonable to prospect that the hybrid of two privileged structures of chromenone and imidazopyridine as demonstrated by the structure of **3a** might be endowed with potent and unique biological and pharmaceutical activities. This prompted us to undertake a thorough study with the aim to develop an efficient and general synthetic approach toward **3**.

Thus, different parameters were screened. It was first found that increasing the amount of $Cu(OAc)_2$ from 0.5 to 1 equiv could improve the yield of **3a** from 18 to 30%. During the course of exploring the effect of different solvents, we found that using a mixture of DMSO and H_2O as the reaction medium was beneficial for the formation of **3a** with an improved yield of 37%. Using other kinds of Pd catalysts, ligands, and bases did not give higher yields of **3a**. Furthermore, considering that the formation of **3a** should first involve a Pd-catalyzed hydroxylation of **1a** to introduce an oxygen atom followed by a Pd-catalyzed carbonylation to introduce the carbonyl unit, we then tried the reaction in a one-pot, step-by-step manner instead of an all-in-one mode to prevent possible adverse effects of carbonylation on hydroxylation or vice versa. Thus, **1a** was initially stirred with $Pd_2(dba)_3$, PPh_3, DABCO, and $Cu(OAc)_2$ in DMSO/H_2O at 120 °C under air for 8 h. Then, the resulting mixture was stirred

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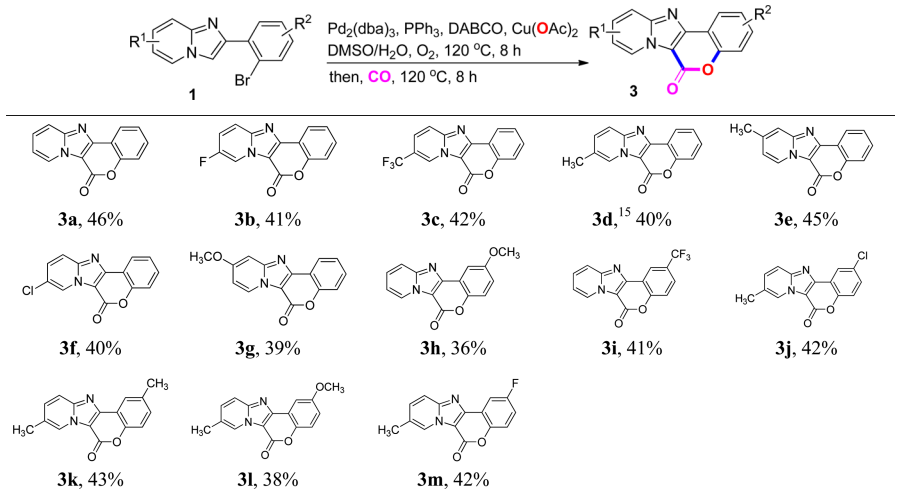
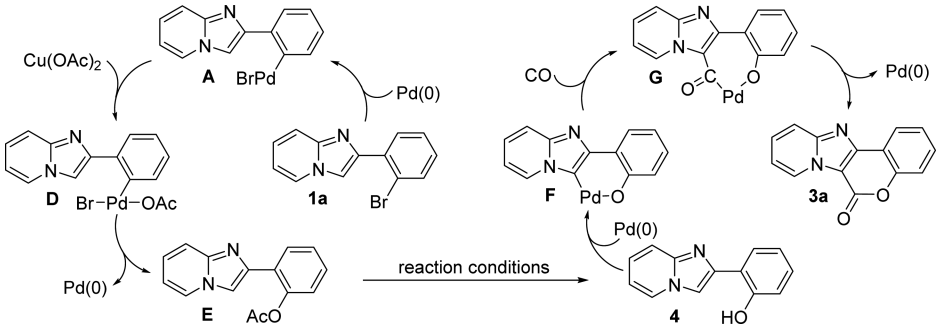
Table 3. Studies on the Generality for the Synthesis of 3[a,b]



[a]Reaction conditions: **1** (0.5 mmol), $Pd_2(dba)_3$ (0.025 mmol), PPh_3 (0.075 mmol), DABCO (1.5 mmol), $Cu(OAc)_2$ (0.5 mmol), DMSO (2 mL), H_2O (0.2 mL), O_2 (1 atm), 120 °C, 8 h; then CO (1 atm), 120 °C, 8 h. [b]Isolated yield.

Scheme 2. Plausible Reaction Pathway for the Formation of 3a



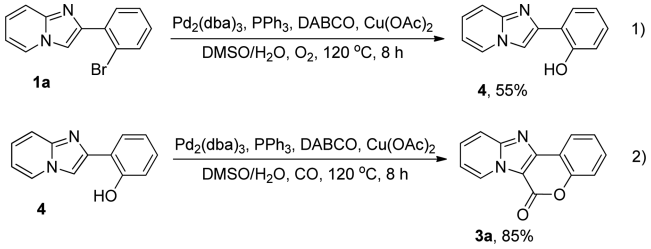
at the same temperature under an atmosphere of CO for another 8 h. With this new procedure, **3a** was obtained in a yield of 43%. Further studies showed that when the first phase (hydroxylation) of this cascade process was carried out under an atmosphere of oxygen instead of air, the yield of **3a** could be improved to 46%. Our studies also revealed that higher reaction temperatures or longer reaction periods did not obviously improve the efficiency.

After optimizing the reaction conditions, we then studied the scope and generality of this novel approach for the synthesis of 6*H*-chromeno[4′,3′:4,5]imidazo[1,2-*a*]pyridin-6-one (**3**). The results listed in Table 3 showed that a number of BPIPs (**1**) with different substituents on the 2-phenyl and/or the IP moieties were suitable substrates for this reaction to afford the corresponding 6*H*-chromeno[4′,3′:4,5]imidazo[1,2-*a*]pyridin-6-ones **3a**–**3m** in moderate yields without showing obvious electronic and steric effects.

While the exact mechanism for the formation of **3a** from **1a** is still unclear, a plausible pathway is proposed based on the literature report.[16] First, acetoxylation of **1a** under the catalysis of palladium gives 2-(imidazo[1,2-*a*]pyridin-2-yl)phenyl acetate (**E**), most likely via intermediates **A** and **D**. Then, **E** is hydrolyzed under the reaction conditions to afford 2-(imidazo[1,2-*a*]-pyridin-2-yl)phenol (**4**). In the next stage of this cascade process, an oxygen-assisted and Pd-catalyzed broken C–H bond affords intermediate **F**. The following coordination of palladium in intermediate **F** with CO followed by a transfer insertion of CO into the C–Pd bond gives intermediate **G**. Finally, reductive elimination occurs with **G** to give **3a** and regenerates the Pd(0) catalyst (Scheme 2).

The reaction pathway as shown in Scheme 2 was partly confirmed by the following control experiments. First, **1a** was treated with $Pd_2(dba)_3$, PPh_3, DABCO, and $Cu(OAc)_2$ in DMSO/H_2O at 120 °C under the atmosphere of O_2 for 8 h. From this reaction, **4** was obtained in a yield of 55% (Scheme 3, eq 1). Second, **4** was treated with $Pd_2(dba)_3$, PPh_3, DABCO, and $Cu(OAc)_2$ in DMSO/H_2O at 120 °C under the atmosphere of CO for 8 h. From this reaction, **3a** was obtained in a yield of 85% (Scheme 3, eq 2).

Scheme 3. Control Experiments Supporting the Proposed Reaction Mechanism for the Formation of 3a from 1a



CONCLUSION

In summary, we have developed a highly selective synthesis of 11*H*-indeno[1′,2′:4,5]imidazo[1,2-*a*]pyridin-11-ones or 6*H*-

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chromeno[4′,3′:4,5]imidazo[1,2-*a*]pyridin-6-ones via palladium-catalyzed cascade reactions of 2-(2-bromophenyl)imidazo[1,2-*a*]pyridines with carbon monoxide under different reaction conditions. To the best of our knowledge, this is the first report of selective preparation of these hybrid compounds via a convenient one-pot procedure starting from easily obtainable substrates. Given the importance of fused heterocycles in synthetic, medicinal, and material chemistry, this new synthetic strategy should find wide applications in related areas. Further study to get deeper insight into the reaction mechanism is currently underway in our laboratories.

EXPERIMENTAL SECTION

General Methods. Unless otherwise noted, all the commercial reagents were used without further purification. The solvents were dried prior to use. 2-(2-Bromophenyl)imidazo[1,2-*a*]pyridines (**1**) were synthesized through condensation of the corresponding 2-aminopyridines with 2-bromophenacyl bromides.[17] Melting points were recorded with a micro melting point apparatus and uncorrected. The ^{1}H NMR spectra were recorded at 400 or 600 MHz. The ^{13}C NMR spectra were recorded at 100 or 150 MHz. Chemical shifts (in ppm) were referenced to tetramethylsilane in $CDCl_3$ or DMSO-d_6. ^{13}C NMR spectra were calibrated with $CDCl_3$ or DMSO-d_6. Multiplicity was indicated as follows: s (singlet), d (doublet), t (triplet), m (multiplet), dd (doublet of doublets), etc., and coupling constants were given in hertz. High-resolution mass spectra (HRMS) were obtained via ESI mode by using a MicrOTOF mass spectrometer. The conversion of starting materials was monitored by thin layer chromatography using silica gel plates (silica gel 60 F254 0.25 mm), and components were visualized by observation under UV light (254 and 365 nm).

Typical Procedure for the Synthesis of 2a−2w and Spectroscopic Data of 2a−2w. To a Schlenk flask containing 2-(2-bromophenyl)-imidazo[1,2-*a*]pyridine (**1a**, 136.6 mg, 0.5 mmol) in DMSO (2 mL) were added $Pd_2(dba)_3$ (46 mg, 0.05 mmol), PPh_3 (20 mg, 0.075 mmol), and DABCO (168.3 mg, 1.5 mmol). After the flask was evacuated and flushed with carbon monoxide, it was stirred at 150 °C under an atmosphere of carbon monoxide (1 atm) for 12 h. Upon completion, it was quenched with saturated NH_4Cl (10 mL) and extracted with EtOAc (6 mL × 3). The combined organic phases were dried over anhydrous Na_2SO_4 and concentrated under vacuum. The residue was purified by column chromatography on silica gel with petroleum ether/ethyl acetate (2:1) as eluent to give **2a** in 68% yield. Other 11*H*-indeno[1′,2′:4,5]-imidazo[1,2-*a*]pyridin-11-one derivatives **2b−2w** were obtained in a similar manner.

*11H-Indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2a**):* R_f = 0.2 (petroleum ether/ethyl acetate, 2:1); yellow solid (75 mg, 68%), mp 241−242 °C (lit.[18] mp 224 °C); IR (KBr) 3005, 1695, 1606, 1559, 1507, 1486, 1414, 769, 758 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.98 (t, J = 6.8 Hz, 1H), 7.19 (t, J = 7.6 Hz, 1H), 7.29−7.40 (m, 4H), 7.60 (d, J = 8.8 Hz, 1H), 8.38 (d, J = 6.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 115.7, 118.5, 119.9, 122.8, 123.5, 127.4, 128.5, 129.9, 133.0, 136.0, 140.1, 154.0, 167.7, 177.7; MS m/z 221 (M + H)$^+$.

*3-Chloro-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2b**):* R_f = 0.3 (petroleum ether/ethyl acetate, 2:1); yellow solid (66 mg, 52%), mp 229−230 °C; IR (KBr) 3103, 1705, 1609, 1558, 1514, 1487, 1427, 880, 814, 771 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.05 (t, J = 7.2 Hz, 1H), 7.19−7.21 (m, 1H), 7.36−7.43 (m, 3H), 7.67 (d, J = 8.8 Hz, 1H), 8.44 (d, J = 6.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 116.0, 118.7, 120.8, 123.2, 124.6, 127.4, 128.9, 129.4, 137.9, 138.2, 139.2, 154.0, 166.2, 176.6; HRMS calcd for $C_{14}H_7ClN_2NaO$ 277.0139 [M + Na]$^+$, found 277.0121.

*2-Methyl-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2c**):* R_f = 0.3 (petroleum ether/ethyl acetate, 2:1); yellow solid (71 mg, 61%), mp 199−200 °C; IR (KBr) 3069, 2928, 1698, 1610, 1493, 1455, 877, 865 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.30 (s, 3H), 6.97 (t, J = 6.8 Hz, 1H), 7.08 (d, J = 7.2 Hz, 1H), 7.23−7.26 (m, 2H), 7.31−7.35 (m, 1H), 7.60 (d, J = 9.2 Hz, 1H), 8.38 (d, J = 6.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.6, 115.6, 118.3, 119.8, 122.6, 124.7, 127.3, 128.4, 132.9, 133.1, 140.3, 140.5, 153.9, 168.0, 178.0; HRMS calcd for $C_{15}H_{11}N_2O$ 235.0866 [M + H]$^+$, found 235.0870.

*2-Fluoro-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2d**):* R_f = 0.2 (petroleum ether/ethyl acetate, 2:1); yellow solid (84 mg, 71%), mp 216−217 °C; IR (KBr) 3064, 1698, 1602, 1511, 1439, 872, 797, 769, 757 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.86 (td, J_1 = 8.4 Hz, J_2 = 2.4 Hz, 1H), 6.92−6.96 (m, 1H), 7.02 (dd, J_1 = 7.6 Hz, J_2 = 2.4 Hz, 1H), 7.23−7.25 (m, 1H), 7.28−7.32 (m, 1H), 7.53 (d, J = 8.8 Hz, 1H), 8.30 (d, J = 6.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 112.5 (d, $^2J_{C-F}$ = 24.6 Hz), 115.9, 118.1 (d, $^2J_{C-F}$ = 23.0 Hz), 118.5, 121.1 (d, $^3J_{C-F}$ = 7.9 Hz), 122.6, 127.5, 128.9, 131.6 (d, $^4J_{C-F}$ = 3.2 Hz), 142.9 (d, $^3J_{C-F}$ = 7.1 Hz), 154.1, 164.2 (d, $^1J_{C-F}$ = 249.3 Hz), 167.4, 175.6; HRMS calcd for $C_{14}H_8FN_2O$ 239.0615 [M + H]$^+$, found 239.0617.

*3-Fluoro-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2e**):* R_f = 0.2 (petroleum ether/ethyl acetate, 2:1); yellow solid (65 mg, 55%), mp 241−242 °C; IR (KBr) 3055, 1702, 1605, 1588, 1455, 1225, 880, 818, 765 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.80 (td, J_1 = 8.0 Hz, J_2 = 2.4 Hz, 1H), 6.98 (t, J = 6.8 Hz, 1H), 7.07 (dd, J_1 = 8.0 Hz, J_2 = 2.4 Hz, 1H), 7.32−7.38 (m, 2H), 7.61 (d, J = 8.8 Hz, 1H), 8.38 (d, J = 6.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 109.1 (d, $^2J_{C-F}$ = 26.2 Hz), 115.2 (d, $^2J_{C-F}$ = 22.2 Hz), 115.9, 118.7, 123.5, 125.4 (d, $^3J_{C-F}$ = 9.6 Hz), 127.3, 128.7, 135.8 (d, $^4J_{C-F}$ = 3.1 Hz), 139.1 (d, $^3J_{C-F}$ = 10.4 Hz), 153.9, 165.6, 166.1 (d, $^1J_{C-F}$ = 251.7 Hz), 176.7; HRMS calcd for $C_{14}H_7FN_2NaO$ 261.0435 [M + Na]$^+$, found 261.0421.

*11H-[1,3]Dioxolo[4″,5″:5′,6′]indeno[1′,2′:4,5]imidazo[1,2-a]-pyridin-11-one (**2f**):* R_f = 0.2 (petroleum ether/ethyl acetate, 2:1); yellow solid (60 mg, 45%), mp 193−194 °C; IR (KBr) 3054, 2886, 1687, 1594, 1497, 1458, 1288, 928, 837, 796, 767 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.96 (s, 2H), 6.88 (s, 1H), 6.91−6.94 (m, 2H), 7.24−7.28 (m, 1H), 7.54 (d, J = 9.2 Hz, 1H), 8.30 (d, J = 6.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 102.1, 102.9, 106.3, 115.8, 118.3, 122.1, 126.9, 127.9, 132.0, 134.5, 148.3, 151.0, 153.7, 167.0, 177.0; HRMS calcd for $C_{15}H_9N_2O_3$ 265.0608 [M + H]$^+$, found 265.0617.

*3-Methoxy-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2g**):* R_f = 0.2 (petroleum ether/ethyl acetate, 2:1); yellow solid (60 mg, 48%), mp 218−219 °C; IR (KBr) 3104, 2924, 1709, 1614, 1545, 1499, 1235, 869, 821, 767 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.87 (s, 3H), 6.62 (dd, J_1 = 8.0 Hz, J_2 = 2.4 Hz, 1H), 6.99−7.03 (m, 2H), 7.33−7.38 (m, 1H), 7.40 (d, J = 8.0 Hz, 1H), 7.65 (d, J = 8.8 Hz, 1H), 8.43 (d, J = 6.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 55.7, 108.5, 111.8, 115.6, 118.5, 123.8, 125.4, 127.1, 128.1, 132.3, 138.5, 153.6, 164.0, 165.9, 177.8; HRMS calcd for $C_{15}H_{11}N_2O_2$ 251.0815 [M + H]$^+$, found 251.0823.

*2-Chloro-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2h**):* R_f = 0.2 (petroleum ether/ethyl acetate, 2:1); yellow solid (74 mg, 58%), mp 229−230 °C; IR (KBr) 3077, 1698, 1605, 1589, 1458, 1180, 806, 770, 766 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.97−7.01 (m, 1H), 7.23 (dd, J_1 = 8.0 Hz, J_2 = 2.0 Hz, 1H), 7.28 (d, J = 7.6 Hz, 1H), 7.33−7.37 (m, 2H), 7.60 (d, J = 8.8 Hz, 1H), 8.37 (d, J = 6.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 116.0, 118.6, 120.9, 122.8, 124.4, 127.6, 129.1, 132.3, 134.2, 136.0, 141.9, 154.3, 167.2, 176.1; HRMS calcd for $C_{14}H_8ClN_2O$ 255.0320 [M + H]$^+$, found 255.0325.

*3-(Trifluoromethyl)-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2i**):* R_f = 0.3 (petroleum ether/ethyl acetate, 2:1); yellow solid (86 mg, 60%), mp 230−231 °C; IR (KBr) 3025, 1705, 1627, 1598, 1454, 1315, 1282, 884, 764 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.09 (t, J = 6.8 Hz, 1H), 7.44−7.48 (m, 1H), 7.53−7.57 (m, 2H), 7.65 (s, 1H), 7.71 (d, J = 9.2 Hz, 1H), 8.48 (d, J = 6.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 116.2, 116.6 (q, $^3J_{C-F}$ = 4.0 Hz), 118.9, 123.3, 123.45, 123.49 (q, $^1J_{C-F}$ = 270.7 Hz), 127.5 (q, $^3J_{C-F}$ = 4.0 Hz), 127.7, 129.4, 134.7 (q, $^2J_{C-F}$ = 31.7 Hz), 136.9, 143.1, 154.4, 166.7, 175.9; HRMS calcd for $C_{15}H_8F_3N_2O$ 289.0583 [M + H]$^+$, found 289.0584.

*8-Methyl-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2j**):* R_f = 0.2 (petroleum ether/ethyl acetate, 2:1); yellow solid (64 mg, 55%), mp 222−223 °C; IR (KBr) 3066, 2928, 1707, 1608, 1590, 1485, 760, 749, 725 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.38 (s, 3H), 7.22−7.25 (m, 2H), 7.32−7.35 (m, 1H), 7.41 (d, J = 6.8 Hz, 1H), 7.46 (d, J = 7.2 Hz, 1H), 7.56 (d, J = 8.8 Hz, 1H), 8.27 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 18.0, 117.7, 119.8, 122.5, 123.5, 125.7, 126.0, 129.8, 131.4,

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133.0, 136.2, 140.3, 153.0, 167.5, 177.8; HRMS calcd for $C_{15}H_{11}N_2O$ 235.0866 $[M + H]^+$, found 235.0871.

8-Fluoro-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2k**): R_f = 0.2 (petroleum ether/ethyl acetate, 2:1); yellow solid (64 mg, 54%), mp 199−200 °C; IR (KBr) 3047, 1695, 1611, 1593, 1487, 1454, 756, 746, 727 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.24−7.31 (m, 2H), 7.37 (t, J = 7.6 Hz, 1H), 7.43 (d, J = 7.2 Hz, 1H), 7.49 (d, J = 7.2 Hz, 1H), 7.64 (dd, J_1 = 10.0 Hz, J_2 = 4.8 Hz, 1H), 8.39 (t, J = 3.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 114.9 (d, $^2J_{C-F}$ = 40.5 Hz), 118.7 (d, $^3J_{C-F}$ = 8.7 Hz), 119.5 (d, $^2J_{C-F}$ = 23.9 Hz), 120.1, 123.9, 130.1, 133.4, 136.0, 139.9, 152.5 (d, $^1J_{C-F}$ = 222.3 Hz), 156.0, 168.1, 177.8; HRMS calcd for $C_{14}H_8FN_2O$ 239.0615 $[M + H]^+$, found 239.0619.

8-Chloro-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2l**): R_f = 0.3 (petroleum ether/ethyl acetate, 2:1); yellow solid (71 mg, 56%), mp 216−217 °C; IR (KBr) 3026, 1702, 1620, 1596, 1455, 1088, 769, 746, 717 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.15−7.19 (m, 1H), 7.24−7.34 (m, 3H), 7.39 (d, J = 7.2 Hz, 1H), 7.51 (d, J = 9.6 Hz, 1H), 8.39 (d, J = 1.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 118.6, 120.2, 123.1, 123.9, 124.0, 125.4, 129.5, 130.2, 133.4, 135.8, 139.8, 152.2, 167.8, 177.8; HRMS calcd for $C_{14}H_8ClN_2O$ 255.0320 $[M + H]^+$, found 255.0323.

7-Methyl-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2m**): R_f = 0.2 (petroleum ether/ethyl acetate, 2:1); yellow solid (71 mg, 61%), mp 199−200 °C; IR (KBr) 3085, 2926, 1697, 1598, 1447, 767, 755, 726 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 2.46 (s, 3H), 6.86 (d, J = 6.8 Hz, 1H), 7.23 (t, J = 7.6 Hz, 1H), 7.32 (t, J = 7.6 Hz, 1H), 7.39- 7.45 (m, 3H), 8.32 (d, J = 6.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.7, 117.4, 118.1, 119.8, 122.3, 123.4, 126.6, 129.9, 132.9, 136.1, 140.3, 140.5, 154.5, 168.3, 177.5; HRMS calcd for $C_{15}H_{11}N_2O$ 235.0866 $[M + H]^+$, found 235.0873.

6-Methyl-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2n**): R_f = 0.2 (petroleum ether/ethyl acetate, 2:1); yellow solid (61 mg, 52%), mp 196−197 °C; IR (KBr) 3022, 2937, 1700, 1607, 1493, 1433, 769, 753, 712 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 2.63 (s, 3H), 6.90 (t, J = 7.2 Hz, 1H), 7.16 (d, J = 7.2 Hz, 1H), 7.19−7.23 (m, 1H), 7.29−7.33 (m, 1H), 7.44 (t, J = 8.0 Hz, 2H), 8.29 (d, J = 6.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 17.2, 115.6, 120.0, 123.2, 123.5, 125.1, 128.0, 128.7, 129.8, 133.0, 136.2, 140.2, 154.1, 167.1, 178.0; HRMS calcd for $C_{15}H_{11}N_2O$ 235.0866 $[M + H]^+$, found 235.0879.

8-(Trifluoromethyl)-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2o**): R_f = 0.3 (petroleum ether/ethyl acetate, 2:1); yellow solid (95 mg, 66%), mp 194−195 °C; IR (KBr) 3058, 1706, 1590, 1458, 1190, 760, 750, 707 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.24 (td, J_1 = 7.6 Hz, J_2 = 1.2 Hz, 1H), 7.34 (td, J_1 = 7.2 Hz, J_2 = 0.8 Hz, 1H), 7.39 (d, J = 7.2 Hz, 1H), 7.44 (d, J = 7.2 Hz, 1H), 7.50 (dd, J_1 = 9.2 Hz, J_2 = 1.2 Hz, 1H), 7.73 (d, J = 9.6 Hz, 1H), 8.72 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 118.9, 119.9 (q, $^2J_{C-F}$ = 34.1 Hz), 120.4, 122.5 (q, $^1J_{C-F}$ = 204.9 Hz), 124.0, 124.2, 125.8 (q, $^3J_{C-F}$ = 5.5 Hz), 130.4, 133.5, 135.5, 139.4, 153.6, 168.8, 177.8; HRMS calcd for $C_{15}H_7F_3N_2NaO$ 311.0403 $[M + Na]^+$, found 311.0382.

11-Oxo-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridine-6-carbonitrile (**2p**): R_f = 0.3 (petroleum ether/ethyl acetate, 2:1); yellow solid (75 mg, 61%), mp 241−242 °C; IR (KBr) 3056, 2237, 1698, 1596, 1437, 767, 755, 709 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6) δ 7.29−7.35 (m, 2H), 7.41−7.49 (m, 3H), 8.15 (dd, J_1 = 7.6 Hz, J_2 = 0.8 Hz, 1H), 8.80 (dd, J_1 = 6.8 Hz, J_2 = 0.8 Hz, 1H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 102.0, 115.2, 116.2, 120.8, 123.9, 124.1, 131.1, 132.8, 134.3, 135.5, 136.1, 139.5, 152.0, 167.5, 177.2; HRMS calcd for $C_{15}H_8N_3O$ 246.0662 $[M + H]^+$, found 246.0675.

2,8-Dimethyl-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2q**): R_f = 0.2 (petroleum ether/ethyl acetate, 2:1); yellow solid (79 mg, 64%), mp 235−236 °C; IR (KBr) 3076, 2924, 1709, 1602, 1487, 1388, 877, 816, 766, 747 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 2.33 (s, 3H), 2.36 (s, 3H), 7.10 (d, J = 7.6 Hz, 1H), 7.20 (dd, J_1 = 8.8 Hz, J_2 = 1.2 Hz, 1H), 7.26−7.28 (m, 2H), 7.51 (d, J = 9.2 Hz, 1H), 8.23 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 18.1, 21.6, 117.6, 119.7, 122.4, 124.7, 125.7, 125.9, 131.2, 132.8, 133.3, 140.2, 140.7, 152.9, 167.8, 178.0; HRMS calcd for $C_{16}H_{13}N_2O$ 249.1022 $[M + H]^+$, found 249.1029.

3-Chloro-8-methyl-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2r**): R_f = 0.3 (petroleum ether/ethyl acetate, 2:1); yellow solid (77 mg, 58%), mp 237−238 °C; IR (KBr) 3066, 2928, 1706, 1612, 1489, 1474, 1439, 1383, 872, 821, 745 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 2.37 (s, 3H), 7.18 (dd, J_1 = 7.6 Hz, J_2 = 2.0 Hz, 1H), 7.24 (dd, J_1 = 9.2 Hz, J_2 = 1.2 Hz, 1H), 7.34−7.36 (m, 2H), 7.54 (d, J = 9.6 Hz, 1H), 8.23 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 18.1, 117.9, 120.6, 122.9, 124.5, 125.7, 126.3, 129.2, 131.7, 138.0, 138.4, 139.0, 152.9, 165.9, 176.5; HRMS calcd for $C_{15}H_{10}ClN_2O$ 269.0476 $[M + H]^+$, found 269.0488.

2-Methyl-8-(trifluoromethyl)-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2s**): R_f = 0.2 (petroleum ether/ethyl acetate, 2:1); yellow solid (104 mg, 69%), IR (KBr) 3079, 2927, 1697, 1614, 1593, 1439, 1376, 855, 818, 747, 703 cm^{-1}; mp 234−235 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 2.35 (s, 3H), 7.15 (d, J = 8.0 Hz, 1H), 7.29−7.31 (m, 2H), 7.50 (dd, J_1 = 9.2 Hz, J_2 = 1.6 Hz, 1H), 7.73 (d, J = 9.6 Hz, 1H), 8.72 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.6, 118.8, 119.8 (q, $^2J_{C-F}$ = 34.2 Hz), 120.3, 122.5 (q, $^1J_{C-F}$ = 189.8 Hz), 124.0 (q, $^3J_{C-F}$ = 2.4 Hz), 124.2, 125.2, 125.7 (q, $^3J_{C-F}$ = 4.8 Hz), 132.7, 133.4, 139.8, 141.0, 153.6, 169.2, 178.1; HRMS calcd for $C_{16}H_{10}F_3N_2O$ 303.0740 $[M + H]^+$, found 303.0744.

8-Chloro-3-(trifluoromethyl)-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2t**): R_f = 0.5 (petroleum ether/ethyl acetate, 2:1); yellow solid (90 mg, 56%), mp 235−236 °C; IR (KBr) 3083, 1697, 1625, 1598, 1453, 1317, 884, 809, 747, 703 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.43 (dd, J_1 = 9.2 Hz, J_2 = 2.0 Hz, 1H), 7.56−7.61 (m, 2H), 7.65−7.67 (m, 2H), 8.53 (t, J = 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 116.9 (q, $^3J_{C-F}$ = 4.0 Hz), 119.0, 122.8 (q, $^1J_{C-F}$ = 142.1 Hz), 123.8, 124.5, 124.8, 125.7, 127.7 (q, $^3J_{C-F}$ = 4.0 Hz), 130.4, 135.0 (q, $^2J_{C-F}$ = 32.5 Hz), 136.7, 142.7, 152.6, 166.7, 175.9; HRMS calcd for $C_{15}H_7ClF_3N_2O$ 323.0194 $[M + H]^+$, found 323.0176.

8-Fluoro-2-methyl-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2u**): R_f = 0.2 (petroleum ether/ethyl acetate, 2:1); yellow solid (80 mg, 64%), mp 206−207 °C; IR (KBr) 3064, 2921, 1702, 1614, 1596, 1458, 873, 819, 746, 713 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 2.26 (s, 3H), 7.05 (d, J = 7.6 Hz, 1H), 7.14−7.21 (m, 3H), 7.51 (dd, J_1 = 10.0 Hz, J_2 = 4.8 Hz, 1H), 8.27 (t, J = 2.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.6, 114.8 (d, $^2J_{C-F}$ = 40.5 Hz), 118.5 (d, $^3J_{C-F}$ = 8.8 Hz), 119.2 (d, $^2J_{C-F}$ = 23.8 Hz), 119.9, 123.8, 125.0, 133.0, 133.2, 140.2, 140.5, 152.5 (d, $^1J_{C-F}$ = 223.2 Hz), 156.0, 168.3 (d, $^4J_{C-F}$ = 3.2 Hz), 178.0; HRMS calcd for $C_{15}H_{10}FN_2O$ 253.0772 $[M + H]^+$, found 253.0779.

3-Methoxy-7-methyl-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2v**): R_f = 0.2 (petroleum ether/ethyl acetate, 2:1); yellow solid (59 mg, 45%), mp 234−235 °C; IR (KBr) 3087, 2926, 1708. 1612, 1593, 1453, 1250, 884, 821, 767 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 2.45 (s, 3H), 3.86 (s, 3H), 6.61 (dd, J_1 = 8.0 Hz, J_2 = 2.0 Hz, 1H), 6.84 (d, J = 6.4 Hz, 1H), 7.00 (d, J = 2.0 Hz, 1H), 7.37−7.40 (m, 2H), 8.30 (d, J = 6.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.7, 55.7, 108.5, 111.6, 117.3, 117.9, 123.3, 125.2, 126.3, 132.4, 138.5, 139.9, 154.0, 163.9, 166.2, 177.5; HRMS calcd for $C_{16}H_{13}N_2O_2$ 265.0972 $[M + H]^+$, found 265.0975.

3-Methoxy-8-methyl-11H-indeno[1′,2′:4,5]imidazo[1,2-a]pyridin-11-one (**2w**): R_f = 0.2 (petroleum ether/ethyl acetate, 2:1); yellow solid (64 mg, 49%), mp 232−233 °C; IR (KBr) 3076, 2924, 1699, 1625, 1596, 1458, 1235, 873, 820, 766 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 2.30 (s, 3H), 3.80 (s, 3H), 6.55 (dd, J_1 = 8.0 Hz, J_2 = 2.4 Hz, 1H), 6.94 (d, J = 2.4 Hz, 1H), 7.13 (dd, J_1 = 9.2 Hz, J_2 = 1.6 Hz, 1H), 7.33 (d, J = 8.0 Hz, 1H), 7.47 (d, J = 9.2 Hz, 1H), 8.18 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 18.1, 55.7, 108.4, 111.7, 117.7, 123.4, 125.3, 125.4, 125.8, 130.9, 132.5, 138.7, 152.6, 164.0, 165.6, 177.8; HRMS calcd for $C_{16}H_{13}N_2O_2$ 265.0972 $[M + H]^+$, found 265.0976.

Typical Synthetic Procedure for the Synthesis of 3a and Spectroscopic Data of 3a−3m. To a flask containing 2-(2-bromophenyl)imidazo[1,2-*a*]pyridine (**1a**, 136.6 mg, 0.5 mmol) in DMSO (2 mL) and H_2O (0.2 mL) were added $Pd_2(dba)_3$ (23 mg, 0.025 mmol), $Cu(OAc)_2$ (90.5 mg, 0.5 mmol), PPh_3 (20 mg, 0.075 mmol), and DABCO (168.3 mg, 1.5 mmol). After the flask was evacuated and flushed with oxygen, it was stirred at 120 °C under an atmosphere of oxygen (1 atm) for 8 h. Then, it was cooled to room temperature, evacuated, and flushed with carbon monoxide. The flask was immersed into an oil bath at 120 °C and stirred under an atmosphere of carbon monoxide (1 atm) for another 8 h. Upon completion, it was quenched with saturated NH_4Cl (10 mL) and extracted with EtOAc (6 mL × 3).

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The combined organic phases were dried over anhydrous Na_2SO_4 and concentrated under vacuum. The residue was purified by column chromatography on silica gel with petroleum ether/ethyl acetate (2:1) as eluent to give **3a** in 46% yield. Other 6*H*-chromeno[4′,3′:4,5]-imidazo[1,2-*a*]pyridin-6-one derivatives **3b**−**3m** were obtained in a similar manner.

*6H-Chromeno[4′,3′:4,5]imidazo[1,2-a]pyridin-6-one (**3a**):* R_f = 0.3 (petroleum ether/ethyl acetate, 2:1); yellow solid (54 mg, 46%), mp 210−211 °C; IR (KBr) 3015, 1729, 1622, 1587, 1189, 749 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.19 (t, J = 7.2 Hz, 1H), 7.43 (t, J = 7.6 Hz, 1H), 7.50 (d, J = 8.4 Hz, 1H), 7.55−7.60 (m, 1H), 7.63−7.67 (m, 1H), 7.87 (d, J = 9.2 Hz, 1H), 8.29 (dd, J_1 = 7.6 Hz, J_2 = 1.2 Hz, 1H), 9.20 (d, J = 6.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 109.7, 114.7, 116.7, 117.5, 123.5, 124.8, 128.1, 130.7, 130.9, 149.9, 150.4, 153.3, 154.8; HRMS calcd for $C_{14}H_9N_2O_2$ 237.0659 $[M + H]^+$, found 237.0665.

*9-Fluoro-6H-chromeno[4′,3′:4,5]imidazo[1,2-a]pyridin-6-one (**3b**):* R_f = 0.4 (petroleum ether/ethyl acetate, 2:1); yellow solid (52 mg, 41%), mp 205−206 °C; IR (KBr) 3027, 1723. 1612, 1599, 1458, 1203, 757 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.44 (t, J = 8.0 Hz, 1H), 7.50 (d, J = 8.0 Hz, 1H), 7.54−7.61 (m, 2H), 7.85 (dd, J_1 = 10.0 Hz, J_2 = 4.4 Hz, 1H), 8.25 (dd, J_1 = 8.0 Hz, J_2 = 1.6 Hz, 1H), 9.15 (t, J = 2.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 110.7, 115.4 (d, $^2J_{C-F}$ = 42.1 Hz), 116.6, 117.6, 117.9 (d, $^3J_{C-F}$ = 8.7 Hz), 122.4 (d, $^2J_{C-F}$ = 24.6 Hz), 123.4, 124.9, 131.1, 147.9, 150.4 (d, $^4J_{C-F}$ = 2.4 Hz), 153.2, 154.0 (d, $^1J_{C-F}$ = 239.8 Hz), 154.7; HRMS calcd for $C_{14}H_8FN_2O_2$ 255.0564 $[M + H]^+$, found 255.0567.

*9-(Trifluoromethyl)-6H-chromeno[4′,3′:4,5]imidazo[1,2-a]-pyridin-6-one (**3c**):* R_f = 0.5 (petroleum ether/ethyl acetate, 2:1); yellow solid (64 mg, 42%), mp 232−233 °C; IR (KBr) 3067, 1732, 1619, 1585, 1458, 1319, 1120, 753 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.45−7.49 (m, 1H), 7.53−7.55(m, 1H), 7.61−7.66 (m, 1H), 7.80 (dd, J_1 = 9.6 Hz, J_2 = 2.0 Hz, 1H), 7.98 (d, J = 9.6 Hz, 1H), 8.30 (dd, J_1 = 8.0 Hz, J_2 = 1.6 Hz, 1H), 9.55 (s,1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 110.5, 116.3, 117.7, 118.2, 119.1 (q, $^2J_{C-F}$ = 35.1 Hz), 123.0 (q, $^1J_{C-F}$ = 270.1 Hz), 123.7, 125.1, 126.6 (q, $^3J_{C-F}$ = 3.3 Hz), 126.9 (q, $^3J_{C-F}$ = 5.4 Hz), 131.6, 150.3, 151.2, 153.4, 154.6; HRMS calcd for $C_{15}H_8F_3N_2O_2$ 305.0532 $[M + H]^+$, found 305.0533.

*9-Methyl-6H-chromeno[4′,3′:4,5]imidazo[1,2-a]pyridin-6-one (**3d**):* R_f = 0.3 (petroleum ether/ethyl acetate, 2:1); yellow solid (50 mg, 40%), mp 203−204 °C; IR (KBr) 3036, 2924, 1724, 1619, 1585, 1457, 1259, 759 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 2.43 (s, 3H), 7.35−7.39 (m, 1H), 7.42−7.45 (m, 2H), 7.52 (td, J_1 = 8.0 Hz, J_2 = 1.6 Hz, 1H), 7.70 (dd, J_1 = 9.2 Hz, J_2 = 3.2 Hz, 1H), 8.19−8.22 (m, 1H), 8.93 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 18.2, 109.3, 116.6, 116.7, 117.4, 123.3, 124.6, 124.9, 125.9, 130.6, 133.6, 149.3, 149.5, 153.1, 154.8; HRMS calcd for $C_{15}H_{11}N_2O_2$ 251.0815 $[M + H]^+$, found 251.0819.

*10-Methyl-6H-chromeno[4′,3′:4,5]imidazo[1,2-a]pyridin-6-one (**3e**):* R_f = 0.4 (petroleum ether/ethyl acetate, 2:1); yellow solid (56 mg, 45%), mp 232−233 °C; IR (KBr) 3064, 2927, 2836, 1726, 1623, 1588, 1454, 1225, 760 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 2.57 (s, 3H), 7.04 (dd, J_1 = 6.8 Hz, J_2 = 1.2 Hz, 1H), 7.42−7.46 (m, 1H), 7.52 (d, J = 8.0 Hz, 1H), 7.57−7.61 (m, 1H), 7.65 (s, 1H), 8.31 (dd, J_1 = 8.0 Hz, J_2 = 1.2 Hz, 1H), 9.08 (d, J = 6.8 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 22.0, 109.4, 116.2, 116.9, 117.2, 117.5, 123.5, 124.7, 127.2, 130.8, 142.7, 150.2, 151.0, 153.3, 154.9; HRMS calcd for $C_{15}H_{11}N_2O_2$ 251.0815 $[M + H]^+$, found 251.0813.

*9-Chloro-6H-chromeno[4′,3′:4,5]imidazo[1,2-a]pyridin-6-one (**3f**):* R_f = 0.4 (petroleum ether/ethyl acetate, 2:1); yellow solid (54 mg, 40%), mp 225−226 °C; IR (KBr) 3095, 1728, 1618, 1585, 1452, 1100, 756 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.46 (t, J = 7.6 Hz, 1H), 7.53 (d, J = 7.6 Hz, 1H), 7.60−7.65 (m, 2H), 7.84 (d, J = 9.6 Hz, 1H), 8.30 (dd, J_1 = 8.0 Hz, J_2 = 1.2 Hz, 1H), 9.29 (d, J = 1.6 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 110.0, 116.5, 117.6, 117.8, 123.0, 123.6, 125.0, 126.1, 131.2, 132.1, 148.7, 150.3, 153.3, 154.7; HRMS calcd for $C_{14}H_8ClN_2O_2$ 271.0269 $[M + H]^+$, found 271.0276.

*10-Methoxy-6H-chromeno[4′,3′:4,5]imidazo[1,2-a]pyridin-6-one (**3g**):* R_f = 0.3 (petroleum ether/ethyl acetate, 2:1); yellow solid (52 mg, 39%), mp 269−270 °C; IR (KBr) 3097, 2921, 2851, 1716, 1621, 1585, 1459, 1255, 1223, 751 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 3.96 (s, 3H), 6.83 (dd, J_1 = 7.6 Hz, J_2 = 2.4 Hz, 1H), 7.11 (d, J = 2.4 Hz, 1H), 7.39−7.43 (m, 1H), 7.49 (d, J = 7.6 Hz, 1H), 7.54−7.58 (m, 1H), 8.24 (dd, J_1 = 8.0 Hz, J_2 = 1.6 Hz, 1H), 8.96 (d, J = 7.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 56.0, 95.5, 109.0, 109.1, 116.8, 117.5, 123.3, 124.7, 128.3, 130.6, 150.6, 152.8, 153.3, 154.7, 162.1; HRMS calcd for $C_{15}H_{11}N_2O_3$ 267.0764 $[M + H]^+$, found 267.0766.

*2-Methoxy-6H-chromeno[4′,3′:4,5]imidazo[1,2-a]pyridin-6-one (**3h**):* R_f = 0.3 (petroleum ether/ethyl acetate, 2:1); yellow solid (48 mg, 36%), mp 245−246 °C; IR (KBr) 3097, 2921, 2851, 1716, 1621, 1585, 1459, 1255, 1036, 751 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 3.94 (s, 3H), 7.14 (dd, J_1 = 8.8 Hz, J_2 = 2.8 Hz, 1H), 7.20 (td, J_1 = 6.8 Hz, J_2 = 0.8 Hz, 1H), 7.42 (d, J = 9.2 Hz, 1H), 7.64−7.68 (m, 1H), 7.69 (d, J = 2.8 Hz, 1H), 7.88 (d, J = 9.2 Hz, 1H), 9.22 (d, J = 6.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 56.0, 104.6, 109.9, 114.7, 117.0, 117.4, 118.7, 119.5, 128.2, 130.8, 147.6, 149.9, 150.3, 155.0, 156.6; HRMS calcd for $C_{15}H_{11}N_2O_3$ 267.0764 $[M + H]^+$, found 267.0769.

*2-(Trifluoromethyl)-6H-chromeno[4′,3′:4,5]imidazo[1,2-a]-pyridin-6-one (**3i**):* R_f = 0.5 (petroleum ether/ethyl acetate, 2:1); yellow solid (62 mg, 41%), mp 225−226 °C; IR (KBr) 3037, 1724, 1632, 1585, 1441, 1317, 897, 848, 752 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 7.17−7.19 (m, 1H), 7.54 (d, J = 8.4 Hz, 1H), 7.62−7.65 (m, 1H), 7.74 (dd, J_1 = 8.4 Hz, J_2 = 1.8 Hz, 1H), 7.84 (d, J = 9.0 Hz, 1H), 8.55 (d, J = 1.2 Hz, 1H), 9.13 (d, J = 6.6 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 110.0, 115.2, 117.1, 117.8, 118.3, 121.4 (q, $^3J_{C-F}$ = 4.5 Hz), 123.7 (q, $^1J_{C-F}$ = 180.1 Hz), 127.3 (q, $^2J_{C-F}$ = 32.7 Hz), 127.5 (q, $^3J_{C-F}$ = 3.3 Hz), 128.2, 131.2, 149.0, 150.7, 154.0, 154.9; HRMS calcd for $C_{15}H_8F_3N_2O_2$ 305.0532 $[M + H]^+$, found 305.0537.

*2-Chloro-9-methyl-6H-chromeno[4′,3′:4,5]imidazo[1,2-a]pyridin-6-one (**3j**):* R_f = 0.5 (petroleum ether/ethyl acetate, 2:1); yellow solid (60 mg, 42%), mp 258−259 °C; IR (KBr) 3047, 1728, 1581, 1371, 1115, 871, 820, 763 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 2.42 (s, 3H), 7.36 (d, J = 8.8 Hz, 1H), 7.42−7.47 (m, 2H), 7.71 (d, J = 9.2 Hz, 1H), 8.19 (d, J = 2.4 Hz, 1H), 8.93 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 18.3, 109.6, 116.9, 118.1, 118.9, 123.1, 125.3, 126.0, 130.3, 130.7, 134.0, 148.7, 149.5, 151.5, 154.5; HRMS calcd for $C_{15}H_{10}ClN_2O_2$ 285.0425 $[M + H]^+$, found 285.0433.

*2,9-Dimethyl-6H-chromeno[4′,3′:4,5]imidazo[1,2-a]pyridin-6-one (**3k**):* R_f = 0.4 (petroleum ether/ethyl acetate, 2:1); yellow solid (57 mg, 43%), mp 205−206 °C; IR (KBr) 3038, 2924, 2856, 1723, 1618, 1585, 1452, 882, 823, 767 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 2.41 (s, 3H), 2.43 (s, 3H), 7.17 (d, J = 7.8 Hz, 1H), 7.23 (s, 1H), 7.41 (dd, J_1 = 9.0 Hz, J_2 = 1.2 Hz, 1H), 7.69 (d, J = 9.6 Hz, 1H), 8.08 (d, J = 7.8 Hz, 1H), 8.94 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 18.2, 21.8, 109.1, 114.2, 116.6, 117.7, 123.1, 124.8, 125.9, 126.1, 133.6, 141.7, 149.5, 150.0, 153.3, 155.2; HRMS calcd for $C_{16}H_{13}N_2O_2$ 265.0972 $[M + H]^+$, found 265.0959.

*2-Methoxy-9-methyl-6H-chromeno[4′,3′:4,5]imidazo[1,2-a]-pyridin-6-one (**3l**):* R_f = 0.3 (petroleum ether/ethyl acetate, 2:1); yellow solid (53 mg, 38%), mp 219−220 °C; IR (KBr) 3084, 2927, 2839, 1724, 1627, 1592, 1149, 853, 814, 763 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 2.48 (s, 3H), 3.94 (s, 3H), 7.12 (dd, J_1 = 9.0 Hz, J_2 = 3.6 Hz, 1H), 7.40 (d, J = 9.0 Hz, 1H), 7.49 (dd, J_1 = 9.0 Hz, J_2 = 1.2 Hz, 1H), 7.67 (d, J = 3.0 Hz, 1H), 7.76 (d, J = 9.0 Hz, 1H), 9.01 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 18.2, 56.0, 104.6, 109.6, 116.6, 117.1, 118.6, 119.3, 124.9, 126.0, 133.7, 147.5, 149.3, 149.6, 155.0, 156.5; HRMS calcd for $C_{16}H_{13}N_2O_3$ 281.0921 $[M + H]^+$, found 281.0927.

*2-Fluoro-9-methyl-6H-chromeno[4′,3′:4,5]imidazo[1,2-a]pyridin-6-one (**3m**):* R_f = 0.3 (petroleum ether/ethyl acetate, 2:1); yellow solid (56 mg, 42%), mp 229−230 °C; IR (KBr) 3036, 2925, 1720, 1491, 1240, 1180, 868, 817, 764 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 2.41 (s, 3H), 7.17−7.21 (m, 1H), 7.39 (dd, J_1 = 9.0 Hz, J_2 = 4.2 Hz, 1H), 7.44 (dd, J_1 = 9.0 Hz, J_2 = 1.2 Hz, 1H), 7.70 (d, J = 9.0 Hz, 1H), 7.86 (dd, J_1 = 7.8 Hz, J_2 = 2.4 Hz, 1H), 8.93 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 18.2, 109.2 (d, $^2J_{C-F}$ = 25.1 Hz), 109.6, 116.9, 118.00 (d, $^3J_{C-F}$ = 8.7 Hz), 118.03 (d, $^2J_{C-F}$ = 24.0 Hz), 119.1 (d, $^3J_{C-F}$ = 8.7 Hz), 125.3, 126.0, 133.9, 148.9, 149.2 (d, $^4J_{C-F}$ = 2.1 Hz), 149.4, 154.6, 159.3 (d, $^1J_{C-F}$ = 243.9 Hz); HRMS calcd for $C_{15}H_{10}FN_2O_2$ 269.0721 $[M + H]^+$, found 269.0724.

Synthetic Procedure and Spectroscopic Data of 4. To a Schlenk flask containing 2-(2-bromophenyl)imidazo[1,2-*a*]pyridine (**1a**, 136.6 mg, 0.5 mmol) in DMSO (2 mL) and H_2O (0.2 mL) were added $Pd_2(dba)_3$ (23 mg, 0.025 mmol), $Cu(OAc)_2$ (90.5 mg, 0.5

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mmol), PPh_3 (20 mg, 0.075 mmol), and DABCO (168.3 mg, 1.5 mmol). After the flask was evacuated and flushed with oxygen, it was stirred at 120 °C under an atmosphere of oxygen (1 atm) for 8 h. Upon completion, it was quenched with saturated NH_4Cl (10 mL) and extracted with EtOAc (6 mL × 3). The combined organic phases were dried over anhydrous Na_2SO_4 and concentrated under vacuum. The residue was purified by chromatography on silica gel with petroleum ether/ethyl acetate (3:1) as eluent to afford **4** in 55% yield.

2-(Imidazo[1,2-a]pyridin-2-yl)phenol (4): R_f = 0.4 (petroleum ether/ethyl acetate, 2:1); yellow solid (58 mg, 55%), mp 146−147 °C (lit.[19] mp 142−143 °C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.82−6.90 (m, 2H), 7.04 (dd, J_1 = 8.4 Hz, J_2 = 0.8 Hz, 1H), 7.19−7.25 (m, 2H), 7.55−7.59 (m, 2H), 7.83 (s, 1H), 8.12 (d, J = 7.2 Hz, 1H), 12.8 (br s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 106.7, 113.2, 116.2, 116.8, 117.7, 119.0, 125.2, 125.4, 125.8, 129.7, 143.5, 145.3, 157.4; MS m/z 211 $(M + H)^+$.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.6b00166.

X-ray crystal structure of **3d** (CIF)

Copies of ^{1}H and ^{13}C NMR spectra (PDF)

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Notes

The authors declare no competing financial interest.

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