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A Facile and Efficient One-Pot Synthesis of Substituted Quinolines from α-Arylamino Ketones Under Vilsmeier Conditions

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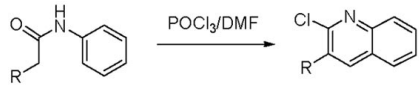
An efficient one-pot synthesis of substituted quinolines from α-arylamino ketones in the presence of PBr_3 in DMF has been developed. This general protocol provides a novel and facile access to substituted quinolines by sequential Vilsmeier–Haack reaction, intramolecular cyclization and aromatization reactions of α-arylamino ketones. PBr_3 plays a dual role in the quinoline synthesis: as a key component of the Vilsmeier reagent (PBr_3/DMF) and as a reducing reagent.

Introduction

Quinolines and related heterocyclic systems represent privileged moieties in medicinal chemistry and are ubiquitous subunits associated with biologically active natural products and synthetic organic compounds.[1–3] Their pharmacological importance and utility as building-blocks in organic synthesis have encouraged considerable research activity towards the synthesis of suitably substituted quinoline rings. Intensive research has generated numerous synthetic approaches, including the conventional named methods of Combes, Skraup, Döbner–Von Miller, Conrad–Limpach, Pfitzinger, Friedländer and Povarov syntheses,[4,5] and the homogeneous metal-catalysed heteroannulation of acyclic precursors.[6,7] Although each of these approaches represents an important advance towards the objective of a general method for the synthesis of quinolines, some of them suffer from significant limitations in terms of the non-availability of precursors, multistep procedures, harsh conditions, low yields, or poor chemo- and regioselectivity. In light of these, simple and efficient methodologies for the construction of the quinoline skeleton are still in demand.

On the other hand, the Vilsmeier–Haack reaction, owing to the mild reaction conditions, commercial availability of the reagents and improved understanding of the reaction mechanism, has been widely used for the formylation of activated aromatic and carbonyl compounds.[8] The versatile reactivity of carbonyl compounds with halomethyleneiminium salts and subsequent cyclization to heterocyclic compounds induced by the Vilsmeier reagent have been well documented.[9] The synthesis of functionalized quinolines by the "Vilsmeier approach" has been explored through the study of the reaction of enamines,[10] *N*-arylacetamides (Scheme 1)[11] or α-oxo ketene *N*,*S*-acetals[12] with Vilsmeier reagents. Recently, Katritzky and Arend reported a highly regioselective one-pot synthesis of 2,3-dialkyl/fused quinolines by cyclocondensation of imines with a novel Vilsmeier reagent derived from *N*-(trimethylsilyl)benzotriazole, DMF and $SOCl_2$.[13] As an alternative, a "reverse Vilsmeier approach" has also been developed by ring-closure of the Vilsmeier reagent derived from *N*-aryl-*N*-methylformamide with electron-rich olefins to give *N*-methylquinolinium salts.[14]



Scheme 1. Meth-Cohn quinoline synthesis.

In our recent work we have demonstrated the utility of the Vilsmeier reagent in the synthesis of functionalized heterocycles, such as substituted 2*H*-pyrans,[15] pyridines,[16] 1*H*-pyrazoles[17] and pyridin-2(1*H*)-ones.[18] Thus, as a continuation of previous work and following on our research interest in the synthesis of highly valuable heterocycles, we have prepared a series of α-arylamino ketones and examined their reactivity towards different Vilsmeier reagents. As a result, we report herein a facile and efficient synthesis of substituted quinolines **2** by Vilsmeier–Haack reactions of the readily available α-arylamino ketones **1**.

Results and Discussion

Substrates **1** were prepared from commercially available 2-bromo-1-arylethanones and arylamines in the presence of

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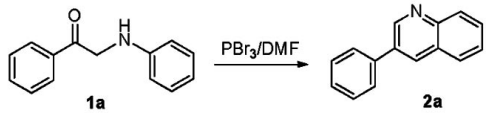
K_2CO_3 in ethanol at room temperature in excellent yields according to the previously reported procedure.[19] With compounds **1a**–**q** in hand, we selected 1-phenyl-2-(phenylamino)ethanone (**1a**) as a model compound to examine its reaction behaviour under Vilsmeier conditions.

Thus, the reaction of **1a** with Vilsmeier reagent PBr_3/DMF (4.0 equiv.) was first attempted at room temperature. The resulting mixture quickly became viscous and finally turned into a brown solid. Unfortunately no product predominated, as indicated by TLC. When **1a** was treated with PBr_3/DMF (4.0 equiv.) at 80 °C, the mixture turned into a solution. The reaction proceeded smoothly and furnished a product after work-up and purification by column chromatography of the resulting mixture. The product was characterized as 3-phenylquinoline (**2a**; 48% yield) on the basis of its spectral and analytical data (Table 1, entry 2). The optimization of the reaction conditions, including reaction temperature and the feed ratio of **1a** to PBr_3/DMF, was then investigated. A series of experiments revealed that 2.0 equiv. of PBr_3/DMF was effective for the synthesis of **2a**; the optimal results were obtained when the reaction of **1a** with 4.0 equiv. of PBr_3/DMF was performed at 120 °C for 3.5 h, which gave a yield of **2a** of 64% (Table 1, entry 4). Note that **2a** was not obtained when subjecting **1a** to another Vilsmeier reagent, $POCl_3$/DMF, at 120 °C for 6.0 h (Table 1, entry 8).

Table 1. Reaction of 1-phenyl-2-(phenylamino)ethanone (**1a**) under Vilsmeier conditions.



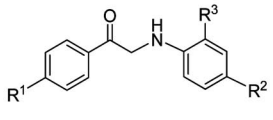
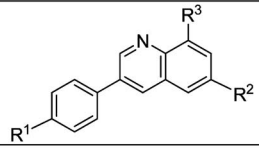
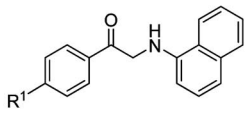
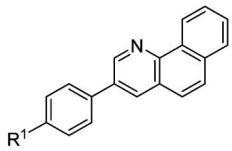
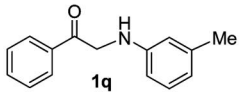
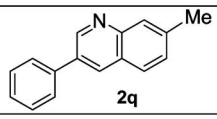
1a **2a**

Entry	Vilsmeier reagent [equiv.]	Temp. [°C]	Time [h]	% Yield[a]
1	PBr_3/DMF (4.0)	r.t.	10.0	0
2	PBr_3/DMF (4.0)	80	10.0	48
3	PBr_3/DMF (4.0)	100	6.0	51
4	PBr_3/DMF (4.0)	120	3.5	64
5	PBr_3/DMF (3.0)	120	6.0	59
6	PBr_3/DMF (2.0)	120	6.0	47
7	PBr_3/DMF (1.0)	120	6.0	15
8	$POCl_3$/DMF (4.0)	120	6.0	0

[a] Isolated yield of **2a**.

Under conditions identical to those used for the preparation of **2a** in Table 1, entry 4, a series of reactions of α-arylamino ketones **1** with PBr_3/DMF (4.0 equiv.) were con-

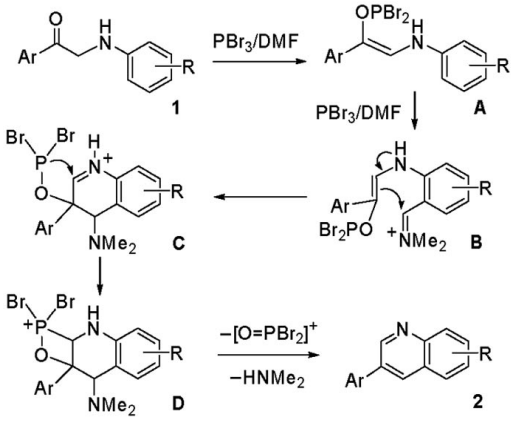
Table 2. Synthesis of substituted quinolines **2** by the Vilsmeier–Haack reaction of α-arylamino ketones **1**.[a]

Entry	Substrate **1**	Product **2**	Yield [%][b]
			
1	**1a**, **2a**: R^1 = H, R^2 = H, R^3 = H		64[7d]
2	**1b**, **2b**: R^1 = H, R^2 = Me, R^3 = H		69
3	**1c**, **2c**: R^1 = H, R^2 = MeO, R^3 = H		71[2f]
4	**1d**, **2d**: R^1 = H, R^2 = Cl, R^3 = H		63
5	**1e**, **2e**: R^1 = H, R^2 = H, R^3 = Me		67
6	**1f**, **2f**: R^1 = H, R^2 = Me, R^3 = Me		75
7	**1g**, **2g**: R^1 = Cl, R^2 = H, R^3 = H		77
8	**1h**, **2h**: R^1 = Cl, R^2 = Me, R^3 = H		80
9	**1i**, **2i**: R^1 = Cl, R^2 = MeO, R^3 = H		78
10	**1j**, **2j**: R^1 = Cl, R^2 = Me, R^3 = Me		82
11	**1k**, **2k**: R^1 = MeO, R^2 = Me, R^3 = H		76
12	**1l**, **2l**: R^1 = MeO, R^2 = MeO, R^3 = H		68
13	**1m**, **2m**: R^1 = MeO, R^2 = Me, R^3 = Me		81
			
14	**1n**, **2n**: R^1 = H		78
15	**1o**, **2o**: R^1 = Cl		75
16	**1p**, **2p**: R^1 = MeO		77
17	 **1q**	 **2q**	72

[a] Reagents and conditions: PBr_3/DMF (4.0 equiv.), 120 °C, 3.5–5.0 h. [b] Isolated yield of **2**; the number in brackets is a reference to known compounds of **2**.

ducted at 120 °C and some of the results are summarized in Table 2. The efficiency of the cyclization proved to be suitable for α-arylamino ketones **1b**–**m**, which afforded the corresponding substituted quinolines **2b**–**m** in good yields (Table 2, entries 2–13). The versatility of the quinoline synthesis was evaluated by performing the reaction with 1-aryl-2-(naphthalen-1-ylamino)ethanones **1n**–**p** (Table 2, entries 14–16). When 2-(*m*-toluidino)-1-phenylethanone (**1q**) was subjected to identical conditions, the reaction furnished a product that was characterized as 7-methyl-3-phenylquinoline (**2q**; Table 2, entry 17). We could not isolate its regioisomer, which might be present in trace amounts in the reaction mixture. The results indicate that the quinoline synthesis exhibits high regioselectivity.

On the basis of all the results obtained, a plausible mechanism for the synthesis of substituted quinolines **2** is presented in Scheme 2. Mediated by Vilsmeier reagent PBr_3/DMF, substrate **1** is first converted into enolate **A** followed by a formylation to give intermediate **B**, which undergoes an intramolecular cyclization to generate iminium ion **C**.[12a–12c,21] Subsequent intramolecular cyclization of **C** leads to the cyclic phosphonium intermediate **D**,[20] which is then aromatized to furnish a substituted quinoline of type **2**. Clearly, the reagent PBr_3 plays a dual role in the quinoline synthesis process: one is as a key component of the Vilsmeier reagent (with DMF) and the other is as a reducing reagent, rather than a halogenated reagent. In fact, tervalent phosphorus compounds (PX_3) such as trialkyl- or triarylphosphanes and diethyl chlorophosphite have been reported as useful reducing reagents in synthetic chemistry.[21] The major driving force for these reactions is the formation of a P=O bond and the release of 120–150 kcal/mol. Therefore, it is not hard to understand why the quinoline synthesis fails when subjecting **1** to another Vilsmeier reagent such as $POCl_3$/DMF.



Scheme 2. Proposed mechanism for the synthesis of quinolines **2**.

Conclusions

We have described a facile and efficient synthesis of substituted quinolines of type **2** from α-arylamino ketones **1** in the presence of PBr_3/DMF by sequential Vilsmeier–Haack reaction, intramolecular cyclization reactions and an aromatization reaction. The simplicity of execution, ready availability of substrates and potentially important use of the products make this synthetic protocol attractive for academic research and practical applications. Further studies towards expanding the scope and synthetic application of this protocol are in progress.

Experimental Section

General: All reagents were purchased from commercial sources and used without treatment unless otherwise indicated. ^1H and ^{13}C NMR spectra were recorded at 25 °C at 500 (or 300) and 125 (or 75) MHz, respectively, using TMS as the internal standard. IR spectra (KBr) were recorded with a FTIR spectrometer in the range of 400–4000 cm^{-1}. Mass spectra were recorded with a LCMsD mass spectrometer.

Typical Procedure for the Synthesis of Substituted Quinolines 2 (with 2a as an example): The Vilsmeier reagent was prepared by adding PBr_3 (8.0 mmol, 0.76 mL) dropwise to ice-cold dry DMF (5 mL) whilst stirring. The mixture was then stirred for 10–15 min at 0 °C. Compound **1a** (2.0 mmol, 0.422 g) was added as a solution in DMF (20 mL) to the above Vilsmeier reagent. Then the mixture was heated to 120 °C and stirred for 3.5 h. After the starting material had been consumed (monitored by TLC), the reaction mixture was poured into a saturated aqueous $NaHCO_3$ solution (50 mL). The mixture was extracted with dichloromethane (3 × 30 mL), the combined organic phase was washed with water (2 × 30 mL), dried with $MgSO_4$, filtered and concentrated in vacuo. The crude product was purified by flash chromatography (silica gel, petroleum ether/ethyl acetate, 10:1) to give **2a** as a viscous liquid (0.262 g, 64% yield).

Physical Data of the Compounds Isolated

2a: Yellowish oil. ^1H NMR ($CDCl_3$, 500 MHz): δ = 7.45 (t, J = 7.5 Hz, 1 H), 7.54 (t, J = 8.0 Hz, 2 H), 7.59 (t, J = 7.0 Hz, 1 H), 7.74 (t, J = 6.5 Hz, 3 H), 7.89 (d, J = 8.0 Hz, 1 H), 8.15 (d, J = 8.5 Hz, 1 H), 8.31 (s, 1 H), 9.20 (s, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 125 MHz): δ = 127.0, 127.4, 128.0, 128.1, 128.8, 128.9, 129.2, 129.4, 133.3, 133.8, 137.8, 147.3, 149.9 ppm. $C_{15}H_{11}N$ (205.25): calcd. C 87.77, H 5.40, N 6.82; found C 87.68, H 5.29, N 6.75.

2b: Yellowish oil. ^1H NMR ($CDCl_3$, 500 MHz): δ = 2.58 (s, 3 H), 7.46 (t, J = 7.5 Hz, 1 H), 7.53–7.58 (m, 3 H), 7.66 (s, 1 H), 7.73 (d, J = 8.0 Hz, 2 H), 8.04 (d, J = 8.5 Hz, 1 H), 8.24 (d, J = 1.0 Hz, 1 H), 9.13 (s, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 125 MHz): δ = 21.6, 126.7, 127.3, 128.0, 129.1, 131.7, 132.6, 133.7, 136.8, 138.0, 145.9, 149.0 ppm. $C_{16}H_{13}N$ (219.28): calcd. C 87.64, H 5.98, N 6.39; found C 87.66, H 5.86, N 6.32.

2c: Yellowish oil. ^1H NMR ($CDCl_3$, 500 MHz): δ = 3.96 (s, 3 H), 7.15 (s, 1 H), 7.38 (d, J = 9.5 Hz, 1 H), 7.44 (t, J = 7.5 Hz, 1 H), 7.53 (t, J = 8.0 Hz, 2 H), 7.71 (d, J = 7.5 Hz, 2 H), 8.03 (d, J = 9.5 Hz, 1 H), 8.21 (s, 1 H), 9.03 (s, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 125 MHz): δ = 55.6, 105.3, 122.2, 127.4, 128.0, 129.1, 130.6, 132.1, 134.1, 138.0, 143.4, 147.4, 158.1 ppm. $C_{16}H_{13}NO$ (235.28): calcd. C 81.68, H 5.57, N 5.95; found C 81.53, H 5.51, N 5.87.

2d: Yellowish oil. ^1H NMR ($CDCl_3$, 300 MHz): δ = 7.45–7.56 (m, 4 H, Ar-H), 7.63–7.71 (m, 2 H), 7.86 (s, 1 H), 8.07 (d, J = 9.0 Hz, 1 H), 8.20 (s, 1 H), 9.17 (s, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 126.6, 127.4, 128.4, 128.7, 128.9, 129.2, 130.2, 130.8, 132.2, 134.7, 137.3, 145.6, 150.1 ppm. $C_{15}H_{10}ClN$ (239.70): calcd. C 75.16, H 4.21, N 5.84; found C 75.31, H 4.18, N 5.91.

2e: Yellowish oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 2.85 (s, 3 H), 7.41–7.47 (m, 2 H), 7.50–7.57 (m, 3 H), 7.72 (t, J = 7.0 Hz, 3 H), 8.26 (d, J = 2.0 Hz, 1 H), 9.12 (d, J = 2.0 Hz, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 18.1, 126.1, 126.8, 127.4, 128.0, 129.2, 129.6, 133.5, 133.6, 137.0, 138.0, 146.4, 148.7 ppm. $C_{16}H_{13}N$ (219.28): calcd. C 87.64, H 5.98, N 6.39; found C 87.56, H 5.87, N 6.49.

2f: Yellowish oil. ^{1}H NMR ($CDCl_3$, 500 MHz): δ = 2.50 (s, 3 H), 2.81 (s, 3 H), 7.42 (t, J = 7.5 Hz, 2 H), 7.48–7.52 (m, 3 H), 7.69–7.71 (m, 2 H), 8.17 (d, J = 2.0 Hz, 1 H), 9.13 (d, J = 2.0 Hz, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 18.0, 21.6, 124.9, 127.4, 127.9, 128.2, 129.0, 129.1, 132.0, 133.0, 133.5, 136.4, 136.6, 138.2, 147.8 ppm. $C_{17}H_{15}N$ (233.31): calcd. C 87.52, H 6.48, N 6.00; found C 87.28, H 6.58, N 5.90.

2g: White solid, m.p. 149–150 °C. ^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.51 (d, J = 8.0 Hz, 2 H), 7.61 (t, J = 7.5 Hz, 1 H), 7.66 (d, J = 8.0 Hz, 2 H), 7.75 (t, J = 7.5 Hz, 1 H), 7.89 (d, J = 8.5 Hz, 1 H), 8.15 (d, J = 8.5 Hz, 1 H), 8.29 (s, 1 H), 9.15 (s, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 125 MHz): δ = 127.2, 127.9, 128.0, 128.6, 129.2, 129.4, 129.6, 133.2, 134.4, 136.3, 149.5, 150.0 ppm. IR (KBr, neat): $\tilde{\nu}$ = 542, 672, 748, 824, 1096, 1356, 1491, 1559 cm^{-1}. $C_{15}H_{10}ClN$ (239.70): calcd. C 75.16, H 4.21, N 5.84; found C 75.40, H 4.15, N 5.73.

2h: White solid, m.p. 151–152 °C. ^{1}H NMR ($CDCl_3$, 500 MHz): δ = 2.56 (s, 3 H), 7.49 (d, J = 8.5 Hz, 2 H), 7.56 (t, J = 7.5 Hz, 1 H), 7.63 (t, J = 6.0 Hz, 3 H), 8.02 (d, J = 9.0 Hz, 1 H), 8.17 (d, J = 1.0 Hz, 1 H), 9.06 (d, J = 1.5 Hz, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 125 MHz): δ = 21.6, 126.7, 127.9, 128.6, 128.9, 129.3, 131.9, 132.5, 132.6, 134.2, 136.5, 137.1, 146.0, 148.6 ppm. IR (KBr, neat): $\tilde{\nu}$ = 459, 515, 827, 917, 1093, 1341, 1490 cm^{-1}. $C_{16}H_{12}ClN$ (253.73): calcd. C 75.74, H 4.77, N 5.52; found C 75.62, H 4.68, N 5.57. MS: calcd. for $C_{16}H_{12}ClN$ [M + 1]$^+$ 253.0; found 254.0.

2i: White solid, m.p. 139–140 °C. ^{1}H NMR ($CDCl_3$, 500 MHz): δ = 3.96 (s, 3 H), 7.13 (d, J = 2.5 Hz, 1 H), 7.38–7.40 (q, J = 7.5 Hz, 1 H), 7.50 (d, J = 8.5 Hz, 2 H), 7.64 (d, J = 8.5 Hz, 2 H), 8.03 (d, J = 9.0 Hz, 1 H), 8.18 (d, J = 1.5 Hz, 1 H), 8.98 (d, J = 2.5 Hz, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 125 MHz): δ = 55.6, 105.2, 122.5, 128.6, 129.0, 129.3, 130.5, 132.1, 132.9, 134.3, 136.4, 143.5, 146.9, 158.2 ppm. IR (KBr, neat): $\tilde{\nu}$ = 506, 829, 1091, 1215, 1455, 1492, 1683 cm^{-1}. $C_{16}H_{12}ClNO$ (269.73): calcd. C 71.25, H 4.48, N 5.19; found C 71.30, H 4.43, N 5.29. MS: calcd. $C_{16}H_{12}ClNO$ [M + 1]$^+$ 269.0; found 270.0.

2j: White solid, m.p. 129–131 °C. ^{1}H NMR ($CDCl_3$, 500 MHz): δ = 2.52 (s, 3 H), 2.81 (s, 3 H), 7.43 (s, 1 H), 7.49 (d, J = 8.5 Hz, 3 H), 7.64 (d, J = 8.5 Hz, 2 H), 8.16 (s, 1 H), 9.09 (d, J = 1.0 Hz, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 18.0, 21.6, 120.3, 124.8, 128.6, 129.3, 132.2, 132.8, 134.1, 136.8, 144.5, 147.4 ppm. $C_{17}H_{14}ClN$ (267.75): calcd. C 76.26, H 5.27, N 5.23; found C 76.24, H 5.35, N 5.13.

2k: White solid, m.p. 137–139 °C. ^{1}H NMR ($CDCl_3$, 500 MHz): δ = 2.56 (s, 3 H), 3.89 (s, 3 H), 7.06 (d, J = 7.5 Hz, 2 H), 7.53 (d, J = 7.5 Hz, 1 H), 7.62 (s, 1 H), 7.65 (d, J = 7.5 Hz, 2 H), 8.01 (d, J = 7.5 Hz, 1 H), 8.16 (s, 1 H), 9.09 (d, J = 1.5 Hz, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 125 MHz): δ = 21.6, 55.4, 114.6, 126.7, 127.0, 128.4, 128.7, 130.4, 131.4, 131.8, 133.4, 136.8, 145.6, 148.9, 160.0 ppm. $C_{17}H_{15}NO$ (249.31): calcd. C 81.90, H 6.06, N 5.62; found C 81.78, H 6.15, N 5.57.

2l: White solid, m.p. 143–145 °C. ^{1}H NMR ($CDCl_3$, 500 MHz): δ = 3.89 (d, J = 2.0 Hz, 3 H), 3.96 (d, J = 1.5 Hz, 3 H), 7.07 (t, J = 6.5 Hz, 2 H), 7.12 (s, 1 H), 7.34–7.37 (q, J = 8.0 Hz, 1 H), 7.66 (t, J = 7.0 Hz, 2 H), 8.00–8.02 (q, J = 7.5 Hz, 1 H), 8.15 (s, 1 H), 9.00 (d, J = 2.5 Hz, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 125 MHz): δ = 55.4, 55.5, 105.1, 114.6, 121.9, 128.5, 129.1, 130.4, 130.5, 131.3, 133.7, 143.1, 147.3, 158.0, 159.7 ppm. IR (KBr, neat): $\tilde{\nu}$ = 676, 833, 1022, 1247, 1286, 1515, 1606 cm^{-1}. $C_{17}H_{15}NO_2$ (265.31): calcd. C 76.96, H 5.70, N 5.28; found C 76.76, H 5.76, N 5.20.

2m: White solid, m.p. 141–143 °C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 2.51 (s, 3 H), 2.82 (s, 3 H), 3.89 (s, 3 H), 6.97 (d, J = 7.5 Hz, 1 H), 7.06 (d, J = 8.1 Hz, 2 H), 7.41 (s, 1 H), 7.48 (s, 1 H), 7.65 (d, J = 7.8 Hz, 2 H), 7.94 (d, J = 8.1 Hz, 1 H), 8.16 (s, 1 H), 9.13 (s, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 18.0, 21.6, 55.4, 113.9, 114.3, 114.6, 124.7, 128.4, 131.7, 132.1, 132.4, 133.1, 136.5, 147.7 ppm. $C_{18}H_{17}NO$ (263.33): calcd. C 82.10, H 6.51, N 5.32; found C 82.40, H 6.43, N 5.43.

2n: White solid, m.p. 196–197 °C. ^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.52 (d, J = 8.5 Hz, 2 H), 7.69–7.79 (m, 6 H), 7.86 (d, J = 9.0 Hz, 1 H), 7.94 (d, J = 8.0 Hz, 1 H), 8.31 (s, 1 H), 9.22 (s, 1 H), 9.29 (d, J = 7.5 Hz, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 125 MHz): δ = 124.3, 125.4, 126.1, 127.3, 127.9, 128.3, 128.4, 128.6, 129.4, 131.2, 133.2, 133.3, 133.6, 134.3, 136.4, 145.7, 147.5 ppm. IR (KBr, neat): $\tilde{\nu}$ = 533, 548, 745, 815, 948, 1012, 1094, 1447 cm^{-1}. $C_{19}H_{13}N$ (255.31): calcd. C 89.38, H 5.13, N 5.49; found C 89.17, H 5.18, N 5.35.

2o: White solid, m.p. 193–194 °C. ^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.52 (d, J = 8.0 Hz, 2 H), 7.69–7.79 (m, 5 H), 7.87 (d, J = 8.5 Hz, 1 H), 7.94 (d, J = 7.5 Hz, 1 H), 8.32 (d, J = 1.5 Hz, 1 H), 9.22 (s, 1 H), 9.29 (d, J = 7.5 Hz, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 125 MHz): δ = 124.3, 125.4, 126.1, 127.3, 127.9, 128.3, 128.4, 128.6, 129.4, 131.2, 133.2, 133.3, 133.6, 134.3, 136.4, 145.7, 147.5 ppm. IR (KBr, neat): $\tilde{\nu}$ = 548, 762, 745, 835, 1012, 1094, 1492, 1513 cm^{-1}. $C_{19}H_{12}ClN$ (289.76): calcd. C 78.76, H 4.17, N 4.83; found C 78.89, H 4.08, N 4.76.

2p: White solid, m.p. 133–134 °C. ^{1}H NMR ($CDCl_3$, 500 MHz): δ = 3.90 (s, 3 H), 7.09 (d, J = 8.5 Hz, 2 H), 7.70–7.78 (m, 3 H), 7.85 (m, 2 H), 7.93 (d, J = 8.5 Hz, 2 H), 8.30 (d, J = 1.5 Hz, 1 H), 9.24 (d, J = 2.0 Hz, 1 H), 9.28 (d, J = 8.0 Hz, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 55.4, 113.6, 114.6, 124.2, 125.5, 127.1, 127.8, 128.0, 128.1, 128.4, 130.6, 132.6, 133.4, 146.9, 147.7, 152.1, 157.3, 159.2 ppm. $C_{20}H_{15}NO$ (285.34): calcd. C 84.19, H 5.30, N 4.91; found C 84.28, H 5.27, N 4.83.

2q: Yellowish oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 2.59 (s, 3 H), 7.43 (t, J = 7.2 Hz, 2 H), 7.52 (t, J = 7.5 Hz, 2 H), 7.70–7.79 (m, 3 H), 7.91 (s, 1 H), 8.25 (d, J = 2.4 Hz, 1 H), 9.14 (d, J = 2.1 Hz, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 21.9, 127.5, 127.56, 127.6, 127.9, 128.0, 128.2, 129.1, 129.2, 133.0, 138.0, 139.7, 147.6, 149.8 ppm. $C_{16}H_{13}N$ (219.28): calcd. C 87.64, H 5.98, N 6.39; found C 87.89, H 5.92, N 6.46.

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