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Iodine monobromide catalysed regioselective synthesis of 3-arylquinolines from α-amino-acetophenones and *trans*-β-nitrostyrenes†

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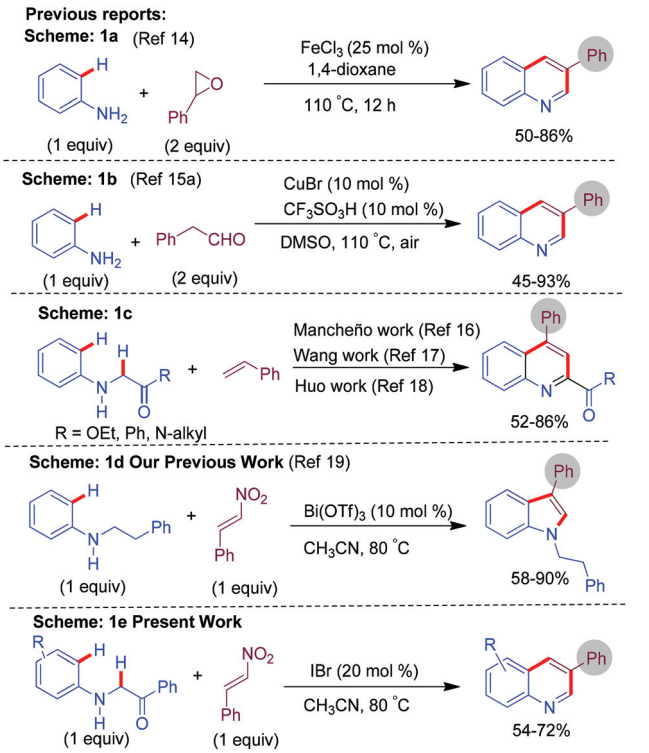
A simple and efficient method for regioselective synthesis of 3-arylquinolines is described from α-aminoacetophenones and *trans*-β-nitrostyrenes using 20 mol% iodine monobromide as a catalyst in acetonitrile solvent at 80 °C. The present method involves tandem reaction of α-aminoacetophenones and *trans*-β-nitrostyrenes, formation of two new C–C bonds and cleavage of one C–C bond in a single step. The salient features of the protocol are metal- and oxidant-free reaction conditions, broad substrate scope, and good yields.

Introduction

Quinoline and its basic skeleton are widely distributed in naturally occurring alkaloids[1] and pharmaceuticals.[2] These quinoline based compounds play a vital role in medicinal chemistry due to various biological properties, such as antimalarial,[3] antimicrobial,[4a] anti-inflammatory,[4b] anthelmintic,[4c] anti-HIV-1[5] and analgesic activities. In addition, optically active quinolines are used in asymmetric synthesis[6] as catalysts and some of them are used as functional materials and metal complexes[7a] for organic light-emitting diodes (OLEDs)[7b] in materials chemisty.[8] Due to wide biological activities and various useful applications, a new synthetic route to synthesize different quinoline derivatives has drawn great attention among synthetic chemists. 3-Arylquinolines are an important class of compounds having biological activities.[9] Various methods have been reported for the synthesis of 3-arylquinolines such as the palladium catalyzed C3-arylation of quinolines through C–H functionalization,[10] Ullmann coupling[11] of *ortho*-acylanilines and alkenyliodides, [4 + 2] hetero Diels–Alder (HDA)[12] reaction of 2-aminobenzyl alcohols with terminal alkynes, and Friedlander-type reaction[13] of *ortho*-aminobenzaldehydes with 3-oxa-2,3-diaryl-propionaldehydes. Recently, Wang *et al.* reported 3-arylquinolines by the $FeCl_3$ promoted tandem reaction of anilines and styrene epoxides[14] (Scheme 1a). Similarly, 3-arylquinolines were also developed from anilines and aldehydes through C–H functionalization (Scheme 1b).[15] Despite the advantages of the reported methods for producing 3-arylquinolines, there are certain limitations such as a small substrate scope and non-availability of substituted styrene epoxide,[14] phenylacetaldehyde[15] and alkenyl iodide[11] derivatives at the commercial scale. The



Scheme 1 Synthetic strategies for the formation of arylquinolines and our previous approach.

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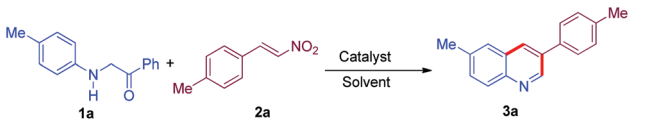
requirement of pre-functionalized anilines like *ortho*-aminobenzylalcohol[13] and *ortho*-aminobenzaldehyde[11,13,20c] derivatives is also another limitation. Therefore, a new method for producing 3-arylquinolines from simple starting materials is always highly desirable to synthetic chemists.

However, Mancheño,[16] Wang[17] and Huo[18] *et al.* reported the reaction of peptides/glycine derivatives with alkenes for the formation of 4-arylquinoline derivatives (Scheme 1c). Recently, we have reported that the reaction of *N*-alkylanilines and *trans*-β-nitrostyrenes resulted in the formation of 3-arylindole derivatives (Scheme 1d).[19] After seeing the notable work of Huo[18] and others,[16,17] we anticipated that by replacing *N*-alkylanilines with α-amino-acetophenones upon reaction with *trans*-β-nitrostyrenes these might provide either 4-arylquinolines or 3-arylquinolines. The literature reveals that *trans*-β-nitrostyrenes[20] are one of the important precursors for the synthesis of five and six membered heterocyclic rings. Iodine monobromide[21] is also found to be well explored in organic synthesis. Herein, we report an alternative method for the regioselective synthesis of 3-arylquinolines through a tandem reaction[22] of α-aminoacetophenones and *trans*-β-nitrostyrenes in acetonitrile at 80 °C using 20 mol% iodine monobromide as a catalyst (Scheme 1e).

Table 1 Optimization of reaction conditions[a,b,c,d]



Entry	Catalyst	Mol%	Solvent	Time (h)	Yield (%)
1	—	—	CH_3CN	24	NR
2[c]	IBr	10	CH_3CN	12	NR
3	IBr	10	CH_3CN	14	62
4	NBS	10	CH_3CN	24	12
5	CBr_4	10	CH_3CN	24	34
6	ICl	10	CH_3CN	24	Trace
7	Iodine	10	CH_3CN	24	NR
8	IBr	20	CH_3CN	10	72
9	IBr	30	CH_3CN	08	66
10	IBr	20	MeOH	24	NR
11	IBr	20	DMSO	24	NR
12[d]	IBr	20	THF	24	NR
13[d]	IBr	20	DCE	14	40

[a] All the reactions were performed using 1-phenyl-2-(*p*-tolylamino) ethanone **1a** (1.0 mmol) and (*E*)-1-methyl-4-(2-nitrovinyl)benzene **2a** (1.0 mmol) at 80 °C. [b] Isolated yield. [c] Reaction performed at room temperature. [d] Reaction performed at 50 °C. NR = no reaction.

Results and discussion

For the present study, various α-aminoacetophenone[23] derivatives (**1a–l**) and *trans*-β-nitrostyrenes[24] (**2a–n**) were prepared by following the reported literature procedures. To find suitable reaction conditions, 1-phenyl-2-(phenylamino)ethanones (**1a**) and (*E*)-1-methyl-4-(2-nitrovinyl)benzene (**2a**) were chosen as the model substrates. Initially the reaction was examined without any catalyst in CH_3CN at 80 °C. It did not give any desired product and the starting material was recovered (Table 1, entry 1). The same reaction was carried out with 10 mol% of IBr in CH_3CN at room temperature, which was also unsuccessful (Table 1, entry 2). Subsequently, the reaction mixture was heated at 80 °C and it resulted in the formation of product **3a** in 62% yield (Table 1, entry 3). The structure of compound **3a** was established through IR, ^{1}H NMR, ^{13}C NMR spectra and HRMS.

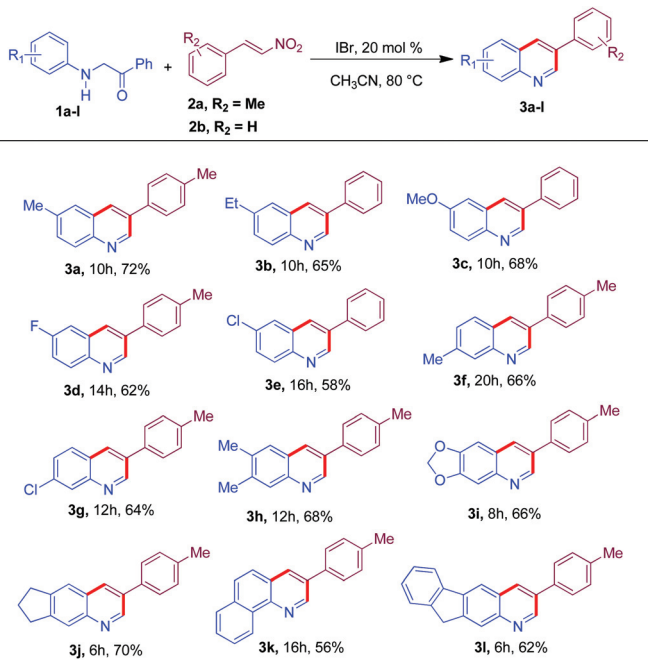
^{1}H NMR shows only nine aromatic protons and two singlets at δ 2.56 and 2.44 for two methyl groups. In addition, no carbonyl carbon signal was present in the ^{13}C spectrum, which clearly indicates the elimination of the benzoyl group. Similarly, there were no absorption peaks for the CO group (at 1650–1700 cm^{-1}) and the NO_2 group (at 1350 cm^{-1} and 1550 cm^{-1}) in the IR spectrum. This clearly shows the elimination of both the benzoyl group and $-NO_2$ group during the course of the reaction.

On screening the identical set of reactions with other catalysts like *N*-bromosuccinimide (NBS) and tetrabromomethane (CBr_4), the yield was found to be 12% and 34%, respectively (Table 1, entries 4 and 5). Furthermore, it was observed that the reaction failed with iodine monochloride (ICl) and molecular iodine under identical conditions (Table 1, entries 6 and 7). Furthermore, in order to improve the yield, the reaction was also examined with 20 mol% of IBr and it was noted that the reaction was completed within 10 h instead of 14 h. At the same time the yield was improved from 62% to 72% (Table 1, entry 8). It is important to mention that there is no further increase in yield by increasing the amount of IBr from 20% to 30 mol% (Table 1, entry 9). The reaction was unsuccessful when it was screened with other solvents such as MeOH, DMSO and THF (Table 1, entries 10–12). Notably, it gave only 40% yield in dichloroethane (DCE) (Table 1, entry 13). Summing up, the best optimized reaction conditions are 20 mol% of IBr in acetonitrile at 80 °C.

With the optimized reaction conditions, the substrate scope was studied with various substituents on the arene ring of the aniline moiety **1** with *trans*-β-nitrostyrenes **2a** and **2b** as represented in Table 2. It is worth mentioning that the substrates having electron donating groups 4-Me, 4-Et, 4-OMe, 3-Me, and 3,4-di-Me and electron withdrawing groups 4-F and 4-Cl on 1-phenyl-2-(phenylamino)ethanone provided the desired products **3a–h** in 58–72% yields.

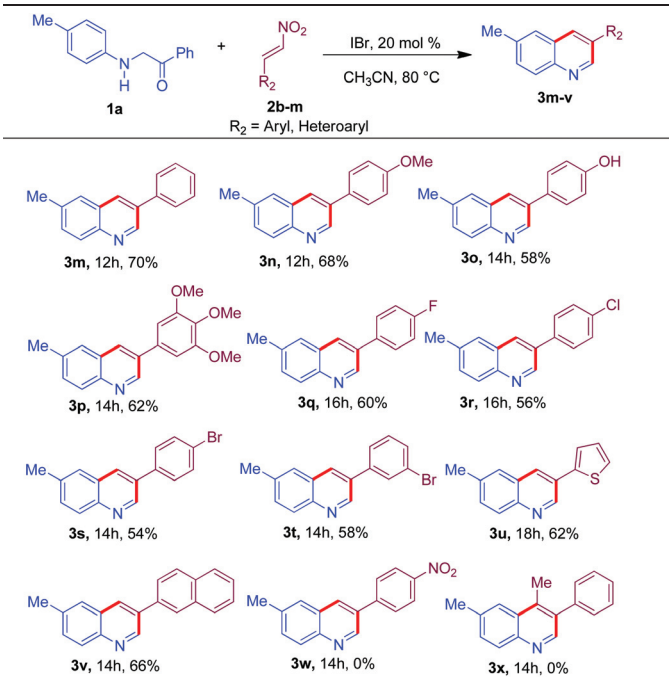
To further extend our synthetic protocol, the reaction was executed with 2-(benzo[*d*][1,3]dioxol-5-ylamino)-1-phenylethanone **1i**, 2-((2,3-dihydro-1*H*-inden-5-yl)amino)-1-phenylethanone **1j** and 2-(naphthalen-1-ylamino)-1-phenylethanone **1k** with (*E*)-1-methyl-4-(2-nitrovinyl)benzene **2a** and it resulted in the formation of the expected products **3i–3k** in 56% and 70% yields. The reaction of 2-((9*H*-fluoren-2-yl)amino)-1-phenylethanone **1l** and (*E*)-1-methyl-4-(2-nitrovinyl)benzene **2a** gave exclusively the **3l** regioisomer. The *ortho*-substituted Me and OMe aniline derivatives were unsuccessful which may be due to steric hindrance. The reaction with electron withdrawing

Table 2 Substrate scope of various substituted anilines with *trans*-β-nitrostyrenes[a,b]



[a] The reactions were carried out using substituted anilines **1a–l** (1 mmol), *trans*-β-nitrostyrenes **2** (1 mmol), CH_3CN (1 mL) and IBr (20 mol%) at 80 °C. [b] Isolated yield.

Table 3 Reaction of 1-phenyl-2-(*p*-tolylamino)ethanone with various *trans*-β-nitrostyrenes[a,b]



[a] The reactions were carried out using 1-phenyl-2-(*p*-tolylamino)ethanone **1a** (1 mmol), *trans*-β-nitrostyrenes **2b–m** (1 mmol), CH_3CN (2 mL) and IBr (20 mol%) at 80 °C. [b] Isolated yield.

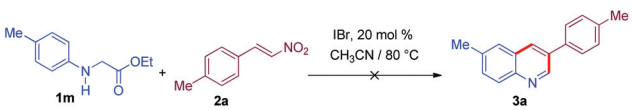
groups such as 4-Br and 4-NO_2 substituents on aniline derivatives also failed to obtain the desired products.

To generalize the present protocol, the substrate scope was further verified with 1-phenyl-2-(*p*-tolylamino)ethanone **1a** and various substituted *trans*-β-nitrostyrenes **2b–i** under optimized reaction conditions and the desired products **3m–3t** were obtained in 54–70% yields as shown in Table 3. The electron donating groups 4-OMe, 4-OH and 3,4,5-tri-OMe groups worked well. Electron withdrawing group(s) on the aromatic ring of *trans*-β-nitrostyrenes such as 4-F, 4-Cl, 4-Br, and 3-Br were also well tolerated. The reaction proceeded well even with a heterocyclic nitrostyrene such as (*E*)-2-(2-nitrovinyl)thiophene **2j** to give the product **3u** in 62% yield. In addition, (*E*)-2-(2-nitrovinyl)naphthalene **2k** was also successful to give the product **3v** in 66% yield.

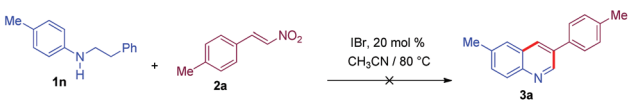
Strong electron withdrawing groups such as the 4-NO_2 substituent on the phenyl ring of *trans*-β-nitrostyrene **2l** failed to provide the desired product **3w**. The reaction with (*E*)-(1-nitroprop-1-en-2-yl)benzene **2m** failed to give compound **3x** due to steric hindrance of the methyl substituent at the β-position of *trans*-β-nitrostyrene.

We have also examined the reaction of ethyl 2-(*p*-tolylamino) acetate **1m** (1 mmol) with (*E*)-1-methyl-4-(2-nitrovinyl)benzene **2a** (1 mmol) under identical reaction conditions, but we did not obtain the expected product **3a** as shown in Scheme 2.

To further verify the substrate scope, we have performed a reaction of 4-methyl-*N*-phenethylaniline **1n** with *trans*-β-nitrostyrene **2a** in the presence of 20 mol% iodine monobromide catalyst under identical reaction conditions. Unfortunately, we did not obtain the expected 3-arylquinoline product as shown in Scheme 3. From this observation, it was seen that the carbonyl group adjacent to the phenyl group plays a crucial role in this particular transformation.

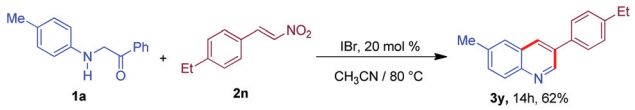


Scheme 2 Reaction of a glycine derivative with *trans*-β-nitrostyrene.



Scheme 3 Reaction of 4-methyl-*N*-phenethylaniline with *trans*-β-nitrostyrene.

To examine the large scale reaction, we have executed the reaction of 1-phenyl-2-(*p*-tolylamino)ethanone **1a** (10 mmol) and (*E*)-1-ethyl-4-(2-nitrovinyl)benzene **2n** (10 mmol) under similar reaction conditions and it gave the product **3y** in 62% yield as shown in Scheme 4.



Scheme 4 Gram scale reaction.

All the synthesized compounds were well characterized by IR, ^{1}H NMR, ^{13}C NMR spectra and HRMS. In addition, the structure of compound **3s** was confirmed through single X-ray crystallographic data (see the ESI†) (Fig. 1).

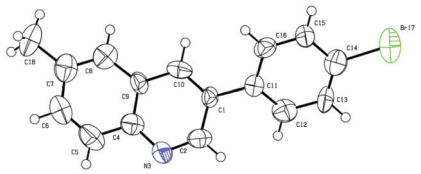
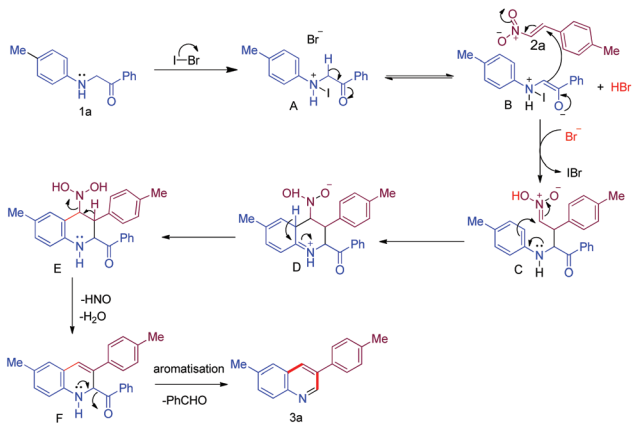


Fig. 1 The ORTEP diagram of **3s** with 40% ellipsoid probability (CCDC no. 1835007†).



Scheme 5 Plausible reaction mechanism for the formation of 3-arylquinolines.

The plausible mechanism for the formation of 3-arylquinolines is depicted in Scheme 5. Initially, 1-phenyl-2-(*p*-tolylamino)ethanone **1a** transforms to intermediate **B** in the presence of IBr, which reacts with *trans*-β-nitrostyrene **2a** to form an intermediate **C** through the formation of a new C–C bond. The intermediate **C** undergoes *ortho*-cyclisation with the arene ring of the aniline to form tetrahydroquinoline **E**, which transforms to dihydroquinoline **F**, which subsequently undergoes aromatisation through elimination of the aldehyde group to form a stable 3-arylquinoline **3a**. The formation of intermediate compound **C** was confirmed by HRMS analysis (see the ESI†).

Conclusions

In summary, we have developed a new protocol for the regioselective synthesis of 3-arylquinolines through the iodine monobromide catalyzed tandem reaction of α-aminoacetophenones and *trans*-β-nitrostyrenes. The advantages of the present protocol are the formation of two new C–C bonds, metal and oxidant free reaction conditions, broad substrate scope and good yields. In addition, the protocol is also useful for the synthesis of 3-heteroaryl quinolines.

Experimental

General information and methods

Melting points were determined on a melting point apparatus and are uncorrected. ^{1}H and ^{13}C NMR spectra were recorded on 400 & 600 MHz and 100 & 150 MHz NMR spectrometers. TMS was used as the internal reference and chemical shifts (δ scale) are reported in parts per million (ppm). ^{1}H NMR spectra are reported in the following order: multiplicity, coupling constant (J value) in hertz (Hz) and no. of protons; signals were characterized as s (singlet), d (doublet), t (triplet), m (multiplet) and bs (broad). IR spectra were recorded on an IR spectrophotometer. HRMS spectra were recorded using an ESI and APCI (TOF) mode. The X-ray crystal structures were determined using a single XRD diffractometer.

General procedure for synthesis of 3-arylquinolines (3a–3y)

A mixture α-aminoacetophenone **1a** (1.0 mmol), *trans*-β-nitrostyrene **2a** (1.0 mmol) and IBr (20 mol%) was taken in a dry 25 mL round bottomed flask in 5 mL of acetonitrile. The reaction mixture was stirred in a heated oil-bath at 80 °C. The progress of the reaction was monitored by TLC. After completion of the reaction, acetonitrile was removed in a rotary evaporator under reduced pressure and the crude residue was then extracted with dichloromethane (2 × 25 mL). The combined organic layer was washed with 25 mL of 10% sodium thiosulfate solution to remove iodine, washed with water and it was dried over anhydrous sodium sulfate. After the removal of organic solvent in a rotary evaporator, the crude residue was purified through silica gel (60–120 mesh) column chromatography and the desired product **3a** was obtained in 72% yield. The desired product was eluted with a mixture of ethyl acetate and petroleum ether (05 : 95). A similar procedure was followed for all other substrates.

6-Methyl-3-(*p*-tolyl)quinoline (3a). Yield 72% (168 mg), colourless liquid, ^{1}H NMR (600 MHz, $CDCl_3$): δ 9.10 (d, J = 2.3 Hz, 1H), 8.22–8.17 (m, 1H), 8.03 (d, J = 8.5 Hz, 1H), 7.64–7.62 (m, 1H), 7.62–7.59 (m, 2H), 7.54 (dd, J = 8.6, 1.9 Hz, 1H), 7.35–7.31 (m, 2H), 2.56 (d, J = 1.0 Hz, 3H), 2.44 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ 149.1, 145.8, 138.2, 137.1, 135.2, 133.9, 132.6, 131.8, 130.1, 128.8, 128.3, 127.4, 126.9, 21.9, 21.4; IR (KBr) ν_{max} 2928, 2972, 1632, 1421, 1084, 1024, 814 cm^{-1}; HRMS (ESI) calcd for $C_{17}H_{16}N$ 234.1277 ($M + H^+$); found 234.1299.

6-Ethyl-3-phenylquinoline (3b). Yield 65% (152 mg), colorless liquid, ^{1}H NMR (600 MHz, $CDCl_3$): δ 9.12 (d, J = 2.3 Hz, 1H), 8.25 (d, J = 2.3 Hz, 1H), 8.06 (d, J = 8.6 Hz, 1H), 7.73–7.70 (m, 2H), 7.66 (d, J = 1.9 Hz, 1H), 7.60 (dd, J = 8.6, 2.0 Hz, 1H), 7.54–7.51 (m, 2H), 7.45–7.43 (m, 1H), 2.90–2.83 (m, 2H), 1.36 (t, J = 7.6 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ 149.2, 146.24,

143.4, 138.2, 134.0, 133.1, 130.9, 129.4, 129.1, 128.3, 128.2, 127.6, 125.7, 29.1, 15.6; IR (KBr) ν_{max} 3033, 2964, 2927, 2954, 1676, 1494, 1261, 834 cm^{-1}; HRMS (ESI) calcd for $C_{17}H_{16}N$ 234.1277 ($M + H^+$); found 234.1266.

6-Methoxy-3-phenylquinoline (3c). Yield 68% (160 mg), white solid, mp 118–119 °C, ^1H NMR (600 MHz, $CDCl_3$): δ 9.03 (d, J = 2.2 Hz, 1H), 8.22 (d, J = 2.2 Hz, 1H), 8.05 (d, J = 9.1 Hz, 1H), 7.74–7.68 (m, 2H), 7.53 (t, J = 7.7 Hz, 2H), 7.45–7.42 (m, 1H), 7.38 (dd, J = 9.2, 2.8 Hz, 1H), 7.14 (d, J = 2.8 Hz, 1H), 3.96 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ 158.4, 147.4, 143.4, 138.2, 134.4, 132.6, 130.5, 129.4, 129.3, 128.3, 127.6, 122.6, 105.5, 55.80; IR (KBr) ν_{max} 2964, 2862, 2781, 1609, 1517, 1258, 1026, 832 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{14}NO$ 236.1070 ($M + H^+$); found 236.1092.

6-Fluoro-3-(*p*-tolyl)quinoline (3d). Yield 62% (147 mg), light yellow color liquid, ^1H NMR (600 MHz, $CDCl_3$): δ 9.15 (d, J = 2.2 Hz, 1H), 8.25 (d, J = 2.2 Hz, 1H), 8.17–8.12 (m, 1H), 7.65–7.62 (m, 2H), 7.51 (dd, J = 8.6, 2.3 Hz, 2H), 7.37 (d, J = 7.8 Hz, 2H), 2.46 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ 161.8, 160.1, 149.4, 144.4, 138.6, 134.7, 134.7, 132.5, 132.4, 131.8, 131.8, 130.2, 127.5, 119.8, 119.6, 111.1, 110.9, 21.4; IR (KBr) ν_{max} 3062, 2928, 2846, 1654, 1348, 1228, 1098, 1024, 924, 828 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{13}FN$ 238.1027 ($M + H^+$); found 238.1042.

6-Chloro-3-phenylquinoline (3e). Yield 58% (139 mg), light brown colour solid, mp 106–108 °C, ^1H NMR (400 MHz, $CDCl_3$): δ 9.17 (d, J = 2.3 Hz, 1H), 8.22 (d, J = 2.2 Hz, 1H), 8.09 (d, J = 8.9 Hz, 1H), 7.87 (d, J = 2.3 Hz, 1H), 7.73–7.69 (m, 2H), 7.66 (dd, J = 9.0, 2.3 Hz, 1H), 7.54 (dd, J = 8.3, 6.7 Hz, 2H), 7.48–7.44 (m, 1H); ^{13}C NMR (150 MHz, $CDCl_3$): δ 150.3, 145.8, 137.6, 134.9, 133.0, 132.5, 130.9, 130.6, 129.5, 128.9, 128.7, 127.7, 126.8; IR (KBr) ν_{max} 3054, 2928, 2852, 1608, 1512, 1098, 1034, 828 cm^{-1}; HRMS (ESI) calcd for $C_{15}H_{11}ClN$ 240.0575 ($M + H^+$); found 240.0597.

7-Methyl-3-(*p*-tolyl)quinoline (3f). Yield 66% (154 mg), colorless liquid, ^1H NMR (600 MHz, $CDCl_3$): δ 9.15 (s, 1H), 8.26 (d, J = 2.2 Hz, 1H), 7.92 (s, 1H), 7.79 (d, J = 8.3 Hz, 1H), 7.65–7.60 (m, 2H), 7.43 (dd, J = 8.3, 1.6 Hz, 1H), 7.37–7.32 (m, 2H), 2.61 (s, 3H), 2.46 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ 150.1, 147.6, 139.8, 138.1, 135.3, 132.8, 130.1, 130.1, 129.4, 128.3, 127.8, 127.6, 127.4, 22.2, 21.4; IR (KBr) ν_{max} 2921, 2978, 1628, 1411, 1092, 817 cm^{-1}; HRMS (ESI) calcd for $C_{17}H_{16}N$ 234.1277 ($M + H^+$); found 234.1287.

7-Chloro-3-(*p*-tolyl)quinoline (3g). Yield 64% (162 mg), colorless liquid, ^1H NMR (600 MHz, $CDCl_3$) δ 9.19 (d, J = 2.3 Hz, 1H), 8.28 (d, J = 2.4 Hz, 1H), 8.15 (d, J = 2.1 Hz, 1H), 7.84 (d, J = 8.7 Hz, 1H), 7.64–7.61 (m, 2H), 7.55 (dd, J = 8.7, 2.1 Hz, 1H), 7.38–7.35 (m, 2H), 2.46 (s, 3H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 151.1, 147.6, 138.6, 135.1, 134.7, 134.2, 132.8, 130.3, 130.2, 129.4, 128.4, 128.3, 127.4, 126.7, 21.4; IR (KBr) ν_{max} 2916, 2850, 1729, 1469, 1180, 1046, 817 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{13}ClN$ 254.0731 ($M + H^+$); found 254.0752.

6,7-Dimethyl-3-(*p*-tolyl)quinoline (3h). Yield 68% (168 mg), yellow liquid, ^1H NMR (600 MHz, $CDCl_3$): δ 9.07 (d, J = 2.2 Hz, 1H), 8.17 (d, J = 2.3 Hz, 1H), 7.88 (s, 1H), 7.61 (d, J = 1.7 Hz, 2H), 7.59 (s, 1H), 7.32 (d, J = 7.9 Hz, 2H), 2.49 (s, 3H), 2.46 (s, 3H), 2.43 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ 149.1, 146.4, 139.8, 138.0, 137.1, 135.5, 133.2, 132.2, 130.0, 128.5, 127.6, 127.4, 127.3, 126.9, 21.4, 20.7, 20.3; IR (KBr) ν_{max} 2928, 2974, 1624, 1414, 1084, 832 cm^{-1}; HRMS (ESI) calcd for $C_{18}H_{18}N$ 248.1434 ($M + H^+$); found 248.1457.

7-(*p*-Tolyl)-[1,3]dioxolo[4,5-*g*]quinoline (3i). Yield 66% (173 mg), yellow liquid, ^1H NMR (600 MHz, $CDCl_3$): δ 8.94 (d, J = 2.3 Hz, 1H), 8.10 (d, J = 2.3 Hz, 1H), 7.57 (d, J = 8.1 Hz, 2H), 7.41 (s, 1H), 7.31 (d, J = 7.9 Hz, 2H), 7.10 (s, 1H), 6.12 (s, 2H), 2.42 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ 150.8, 148.4, 147.4, 138.0, 135.2, 132.6, 132.4, 130.0, 128.4, 127.2, 125.4, 105.6, 103.0, 101.9, 21.4; IR (KBr) ν_{max} 2921, 2851, 1642, 1466, 1025, 993 cm^{-1}; HRMS (ESI) calcd for $C_{17}H_{14}NO_2$ 264.1019 ($M + H^+$); found 264.1024.

3-(*p*-Tolyl)-7,8-dihydro-6*H*-cyclopenta[*g*]quinoline (3j). Yield 70% (181 mg), yellow liquid, ^1H NMR (600 MHz, $CDCl_3$): δ 9.08 (d, J = 2.3 Hz, 1H), 8.21 (d, J = 2.3 Hz, 1H), 7.93 (s, 1H), 7.68 (s, 1H), 7.63 (d, J = 8.0 Hz, 2H), 7.34 (d, J = 7.8 Hz, 2H), 3.15 (td, J = 7.4, 1.3 Hz, 2H), 3.13–3.07 (m, 2H), 2.45 (s, 3H), 2.23–2.18 (m, 2H); ^{13}C NMR (150 MHz, $CDCl_3$): δ 148.8, 147.8, 147.1, 144.6, 137.9, 135.5, 132.9, 132.7, 130.0, 127.5, 127.3, 123.5, 122.1, 33.1, 32.7, 26.4, 21.4; IR (KBr) ν_{max} 2920, 1648, 1468, 1260, 1084, 924, 860 cm^{-1}; HRMS (ESI) calcd for $C_{19}H_{18}N$ 260.1434 ($M + H^+$); found 260.1438.

3-(*p*-Tolyl)benzo[*h*]quinoline (3k). Yield 56% (151 mg), colorless liquid, ^1H NMR (600 MHz, $CDCl_3$) δ 9.31 (d, J = 8.1 Hz, 1H), 9.27 (d, J = 2.3 Hz, 1H), 8.35 (d, J = 2.3 Hz, 1H), 7.95 (d, J = 7.8 Hz, 1H), 7.87 (d, J = 8.8 Hz, 1H), 7.77 (d, J = 8.6 Hz, 2H), 7.74–7.71 (m, 1H), 7.69 (d, J = 8.0 Hz, 2H), 7.38 (d, J = 7.9 Hz, 2H), 2.47 (s, 3H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 148.1, 145.5, 138.3, 135.2, 134.7, 133.7, 133.3, 131.6, 130.1, 128.4, 128.3, 128.1, 127.4, 127.4, 126.5, 125.7, 124.5, 21.4; IR (KBr) ν_{max} 2916, 2850, 1735, 1656, 1458, 1046, 799 cm^{-1}; HRMS (ESI) calcd for $C_{20}H_{16}N$ 270.1277 ($M + H^+$); found 270.1294.

2-(*p*-Tolyl)-11*H*-indeno[2,1-*f*]quinoline (3l). Yield 62% (190 mg), light yellow semi solid, ^1H NMR (600 MHz, $CDCl_3$) δ 9.15 (d, J = 2.3 Hz, 1H), 8.42 (d, J = 2.2 Hz, 1H), 8.26 (s, 1H), 8.21 (s, 1H), 7.96 (d, J = 7.5 Hz, 1H), 7.65 (d, J = 7.9 Hz, 2H), 7.61 (d, J = 7.4 Hz, 1H), 7.45 (t, J = 7.4 Hz, 1H), 7.41 (td, J = 7.4, 1.1 Hz, 1H), 7.36 (d, J = 7.8 Hz, 2H), 4.18 (s, 2H), 2.45 (s, 3H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 148.7, 145.7, 144.2, 141.9, 140.4, 138.3, 135.1, 133.8, 133.6, 130.2, 129.1, 128.4, 127.9, 127.4, 127.4, 125.7, 124.4, 121.1, 117.6, 36.9, 21.4; IR (KBr) ν_{max} 2918, 2850, 1731, 1645, 1467, 1045, 721 cm^{-1}; HRMS (ESI) calcd for $C_{23}H_{18}N$ 308.1434 ($M + H^+$); found 308.1459.

6-Methyl-3-phenylquinoline (3m). Yield 70% (154 mg), white solid, mp 61–62 °C, ^1H NMR (400 MHz, $CDCl_3$): δ 9.11 (d, J = 2.2 Hz, 1H), 8.22 (d, J = 2.2 Hz, 1H), 8.03 (d, J = 8.6 Hz, 1H), 7.73–7.69 (m, 2H), 7.66–7.64 (m, 1H), 7.56 (d, J = 8.8 Hz, 1H), 7.54–7.51 (m, 2H), 7.44 (t, J = 6.7 Hz, 1H), 2.57 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ 149.2, 146.2, 138.3, 137.1, 134.0, 132.9, 131.9, 129.4, 129.1, 128.2, 127.6, 127.0, 21.9; IR (KBr) ν_{max} 3054, 2927, 2824, 1644, 1514, 1324, 1236, 1214, 1042, 922 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{14}N$ 220.1121 ($M + H^+$); found 220.1141.

3-(4-Methoxyphenyl)-6-methylquinoline (3n). Yield 68% (170 mg), yellow solid, 136–137 °C, ^1H NMR (600 MHz, $CDCl_3$):

δ 9.09 (d, J = 2.2 Hz, 1H), 8.17 (d, J = 2.3 Hz, 1H), 8.02 (d, J = 8.6 Hz, 1H), 7.66–7.63 (m, 2H), 7.62 (s, 1H), 7.53 (dd, J = 8.6, 2.0 Hz, 1H), 7.07–7.03 (m, 2H), 3.88 (s, 3H), 2.56 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ 159.9, 149.0, 145.6, 137.1, 133.7, 133.2, 131.7, 130.6, 128.8, 128.7, 126.9, 114.8, 55.6, 21.9; IR (KBr) ν_{max} 2922, 2851, 1716, 1607, 1514, 1251, 1028, 830 cm^{-1}; HRMS (ESI) calcd for $C_{17}H_{16}NO$ 250.1226 (M + H$^+$); found 250.1248.

4-(6-Methylquinolin-3-yl)phenol (3o). Yield 58% (136 mg), light yellow liquid, ^{1}H NMR (600 MHz, $CDCl_3$): δ 9.07 (d, J = 2.3 Hz, 1H), 8.16 (d, J = 2.3 Hz, 1H), 8.01 (d, J = 8.6 Hz, 1H), 7.62 (s, 1H), 7.62–7.58 (m, 2H), 7.53 (dd, J = 8.6, 2.0 Hz, 1H), 7.00 (d, J = 8.6 Hz, 2H), 2.56 (s, 3H); ^{13}C NMR (400 MHz, $CDCl_3$): δ 156.1, 149.0, 145.7, 137.1, 133.6, 132.1, 131.7, 130.8, 128.9, 128.9, 128.4, 126.9, 116.3, 21.9; IR (KBr) ν_{max} 2927, 2857, 1749, 1637, 1514, 1076, 834 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{14}NO$ 236.1070 (M + H$^+$); found 236.1091.

6-Methyl-3-(3,4,5-trimethoxyphenyl)quinoline (3p). Yield 62% (192 mg), yellow color liquid, ^{1}H NMR (600 MHz, $CDCl_3$): δ 9.07 (d, J = 2.1 Hz, 1H), 8.18 (d, J = 2.2 Hz, 1H), 8.04 (d, J = 8.6 Hz, 1H), 7.66 (s, 1H), 7.56 (dd, J = 8.6, 1.9 Hz, 1H), 6.88 (s, 2H), 3.97 (s, 6H), 3.92 (s, 3H), 2.57 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 154.0, 149.1, 146.1, 138.5, 137.2, 134.2, 134.1, 132.7, 131.9, 129.0, 128.2, 126.9, 104.9, 61.2, 56.5, 21.9; IR (KBr) ν_{max} 2926, 2854, 1720, 1612, 1521, 1248, 1022, 824 cm^{-1}; HRMS (ESI) calcd for $C_{19}H_{20}NO_3$ 310.1438 (M + H$^+$); found 310.1452.

3-(4-Fluorophenyl)-6-methylquinoline (3q). Yield 60% (142 mg), white semi solid, ^{1}H NMR (400 MHz, $CDCl_3$): δ 9.05 (d, J = 2.3 Hz, 1H), 8.19 (d, J = 2.3 Hz, 1H), 8.02 (d, J = 8.6 Hz, 1H), 7.65–7.60 (m, 3H), 7.56 (dd, J = 8.5, 1.9 Hz, 1H), 7.51–7.47 (m, 2H), 2.57 (s, 3H); ^{13}C NMR (600 MHz, $CDCl_3$): δ 163.9, 162.3, 148.9, 146.1, 137.3, 134.4, 134.4, 133.1, 132.7, 132.1, 129.8, 129.3, 129.2, 129.0, 128.2, 126.9, 116.4, 116.3, 21.9; IR (KBr) ν_{max} 3061, 2924, 2855, 1653, 1600, 1231, 1099, 1037, 917, 831 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{13}FN$ 238.1027 (M + H$^+$); found 238.1018.

3-(4-Chlorophenyl)-6-methylquinoline (3r). Yield 56% (142 mg), brown color solid, mp 150–151 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 9.05 (d, J = 2.3 Hz, 1H), 8.19 (d, J = 2.3 Hz, 1H), 8.02 (d, J = 8.6 Hz, 1H), 7.65–7.60 (m, 3H), 7.56 (dd, J = 8.5, 1.9 Hz, 1H), 7.51–7.47 (m, 2H), 2.57 (s, 3H); ^{13}C NMR (600 MHz, $CDCl_3$): δ 148.7, 146.2, 137.4, 136.7, 134.5, 132.9, 132.8, 132.2, 129.6, 129.5, 128.9, 128.8, 128.2, 127.0, 21.8; IR (KBr) ν_{max} 3024, 2922, 2852, 1607, 1513, 1252, 1090, 1026, 829 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{13}ClN$ 254.0731 (M + H$^+$); found 254.0749.

3-(4-Bromophenyl)-6-methylquinoline (3s). Yield 54% (160 mg), white solid, mp 180–181 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 9.06 (d, J = 2.3 Hz, 1H), 8.19 (dd, J = 2.3, 0.8 Hz, 1H), 8.03 (d, J = 8.6 Hz, 1H), 7.67–7.64 (m, 1H), 7.64 (d, J = 2.0 Hz, 2H), 7.58–7.57 (m, 2H), 7.56 (d, J = 1.9 Hz, 1H), 2.56 (s, 3H); ^{13}C NMR (600 MHz, $CDCl_3$): δ 148.6, 146.1, 137.4, 137.1, 132.9, 132.5, 132.3, 129.1, 128.9, 128.2, 127.0, 122.7, 21.9; IR (KBr) ν_{max} 2921, 2854, 1651, 1484, 1078, 825 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{13}BrN$ 298.0226 (M + H$^+$); found 298.0245 and 300.0236.

3-(3-Bromophenyl)-6-methylquinoline (3t). Yield 58% (174 mg), white semi solid, ^{1}H NMR (600 MHz, $CDCl_3$) δ 9.06 (d, J = 2.3 Hz, 1H), 8.20 (d, J = 2.2 Hz, 1H), 8.04 (d, J = 8.6 Hz, 1H), 7.84 (t, J = 1.9 Hz, 1H), 7.64 (s, 1H), 7.63 (dt, J = 7.7, 1.3 Hz, 1H), 7.57 (td, J = 8.3, 7.9, 1.6 Hz, 2H), 7.39 (t, J = 7.8 Hz, 1H), 2.57 (s, 3H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 148.6, 146.2, 140.3, 137.4, 133.2, 132.6, 132.4, 131.2, 130.9, 130.6, 128.9, 128.1, 127.1, 126.2, 123.4, 21.9; IR (KBr) ν_{max} 2924, 2858, 1648, 1482, 1072, 821 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{13}BrN$ 298.0226 (M + H$^+$); found 298.0251 and 300.0232.

6-Methyl-3-(thiophen-2-yl)quinoline (3u). Yield 62% (140 mg), colorless liquid, ^{1}H NMR (400 MHz, $CDCl_3$): δ 9.13 (d, J = 2.3 Hz, 1H), 8.19 (d, J = 2.3 Hz, 1H), 7.99 (d, J = 8.6 Hz, 1H), 7.60 (d, J = 1.7 Hz, 1H), 7.52 (dd, J = 8.6, 2.0 Hz, 1H), 7.49 (dd, J = 3.6, 1.1 Hz, 1H), 7.39 (dd, J = 5.1, 1.2 Hz, 1H), 7.17 (dd, J = 5.1, 3.6 Hz, 1H), 2.55 (s, 3H); δ ^{13}C NMR (101 MHz, $CDCl_3$) δ 147.9, 146.1, 141.2, 137.4, 131.9, 131.1, 129.1, 128.6, 128.2, 127.8, 126.8, 126.2, 124.5, 21.8; IR (KBr) ν_{max} 2932, 2858, 1648, 1466, 1068, 832 cm^{-1}; HRMS (ESI) calcd for $C_{14}H_{12}NS$ 226.0685 (M + H$^+$); found 226.0709.

6-Methyl-3-(naphthalen-2-yl)quinoline (3v). Yield 66% (178 mg), white semisolid, ^{1}H NMR (600 MHz, $CDCl_3$) δ 9.25 (d, J = 2.3 Hz, 1H), 8.36 (d, J = 2.2 Hz, 1H), 8.19–8.16 (m, 1H), 8.06 (d, J = 8.5 Hz, 1H), 8.00 (d, J = 8.5 Hz, 1H), 7.98–7.94 (m, 1H), 7.91 (dd, J = 7.4, 1.7 Hz, 1H), 7.85 (dd, J = 8.5, 1.9 Hz, 1H), 7.69 (s, 1H), 7.58 (dd, J = 8.4, 1.9 Hz, 1H), 7.55 (td, J = 7.1, 1.6 Hz, 2H), 2.61–2.52 (m, 3H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 149.3, 145.9, 137.3, 135.5, 133.9, 133.8, 133.3, 133.1, 132.1, 129.2, 128.9, 128.5, 128.4, 127.9, 127.1, 126.9, 126.7, 126.6, 125.5, 21.9; IR (KBr) ν_{max} 2932, 2868, 1656, 1472, 1068, 832 cm^{-1}; HRMS (ESI) calcd for $C_{20}H_{16}N$ 270.1277 (M + H$^+$); found 270.1300.

3-(4-Ethylphenyl)-6-methylquinoline (3y). Yield 62% (1.54 g), brown liquid, ^{1}H NMR (600 MHz, $CDCl_3$) δ 9.11 (d, J = 2.3 Hz, 1H), 8.19 (d, J = 2.3 Hz, 1H), 8.02 (d, J = 8.6 Hz, 1H), 7.66–7.61 (m, 3H), 7.54 (dd, J = 8.6, 1.9 Hz, 1H), 7.36 (d, J = 7.9 Hz, 2H), 2.73 (q, J = 7.6 Hz, 2H), 2.56 (s, 3H), 1.30 (t, J = 7.6 Hz, 3H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 149.2, 145.9, 144.5, 137.0, 135.5, 133.9, 132.5, 131.8, 131.7, 128.9, 128.9, 128.3, 127.5, 126.9, 28.8, 21.9, 15.8; IR (KBr) ν_{max} 3025, 2964, 2828, 1499, 1345, 1019, 833 cm^{-1}; HRMS (ESI) calcd for $C_{18}H_{18}N$ 248.1434 (M + H$^+$); found 248.1459.

Conflicts of interest

There are no conflicts to declare.

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