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Efficient microwave-assisted synthesis of quinolines and dihydroquinolines under solvent-free conditions

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Abstract—A convenient and efficient procedure for the synthesis of quinolines and dihydroquinolines has been developed by a simple one-pot reaction of anilines with alkyl vinyl ketones on the surface of silica gel impregnated with indium(III) chloride under microwave irradiation without any solvent.

1. Introduction

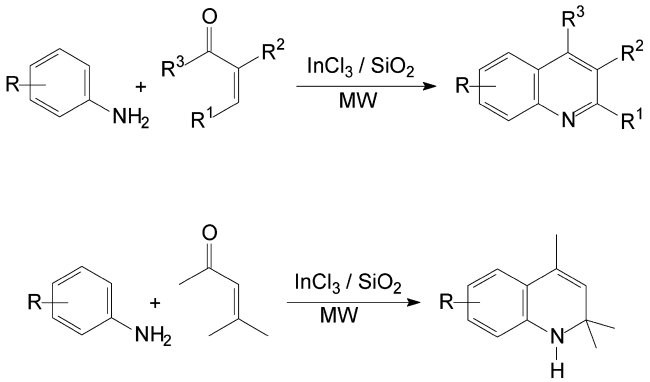
The synthesis of the quinoline ring has been the subject of continued interest as several derivatives of this heterocyclic unit have been found to possess useful biological activities such as bactericidal,[1] antimalarial,[2] antiinflammatory[3] etc. The classical method for quinoline synthesis involves Skraup's procedure.[4] However, it requires a large amount of sulfuric acid at temperatures above 150°C and the reaction is often violent. A number of other methods[5] have been reported for the synthesis of quinolines involving a variety of metal catalysts and Lewis acids. However, many of these procedures are not fully satisfactory with regard to operational simplicity, cost of the reagent and isolated yield. Thus, the drive is continues to find a better and improved methodology. In a recent communication[6] we have demonstrated a very simple procedure for the synthesis of 4-alkylquinolines by a one-pot reaction of anilines and alkyl vinyl ketones on the surface of silica gel impregnated with indium(III) chloride under microwave irradiation without any-solvent and we report here further manipulation of this methodology for the synthesis of dihydroquinolines together with the experimental details of our earlier results (Scheme 1).

2. Results and discussion

The experimental procedure is very simple. A mixture of aniline and alkyl vinyl ketone was added to silica gel impregnated with indium(III) chloride (30 mol%) and the whole mass was stirred for 5 min for uniform mixing. The mixture was then irradiated by microwave in a domestic microwave oven for a few minutes as required to complete the reaction. The reaction mixture was then eluted with ethyl acetate and the extract was washed with brine, dried and evaporated to leave the crude product which was purified by column chromatography over silica gel.

A wide range of substituted anilines and structurally diverse alkyl vinyl ketones were subjected to this procedure to produce the corresponding quinolines or dihydroquinolines in high yields. When an unsubstituted or an α/β-monosubstituted alkyl vinyl ketone is used, quinolines are obtained and the results are summarized in Table 1. However, use of a β-disubstituted alkyl vinyl ketone such as mesityl oxide leads to the construction of a dihydroquinoline ring. This is quite expected as the presence of two methyl groups at the carbon adjacent to –NH (Scheme 1) prevents aromatisation to the quinoline ring. The results are presented in Table 2.

As evident from the results in Table 1 this procedure offers



Scheme 1.

Keywords: quinoline; 1,2-dihydroquinoline; indium trichloride; microwave activation.

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Table 1. Synthesis of quinolines

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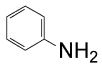
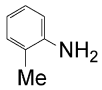
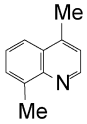
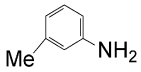
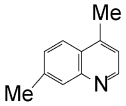
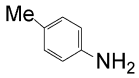
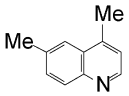
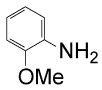
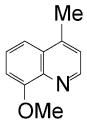
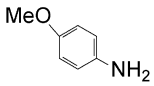
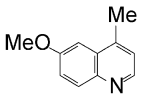
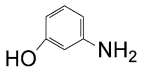
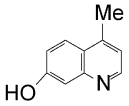
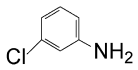
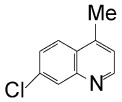
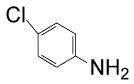
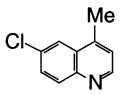
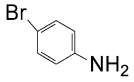
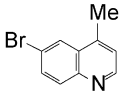
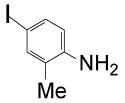
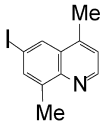
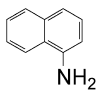
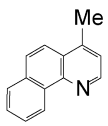
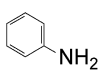
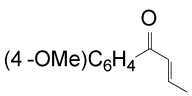
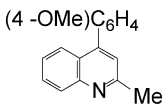
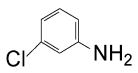
1			5		85
2			10		81
3			10		84
4			10		85
5			12		80
6			10		83
7			10		81
8			5		87
9			12		80
10			7		80
11			10		83
12			7		82
13			9		81
14			7		83
15			12		55

[a] Yields refer to those of pure isolated products fully characterized by spectral (IR, ^{1}H and ^{13}C NMR) and analytical data.

Table 2. Synthesis of dihydroquinolines

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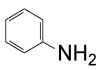
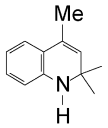
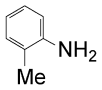
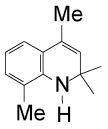
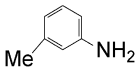
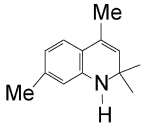
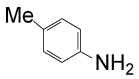
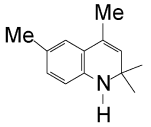
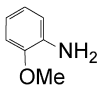
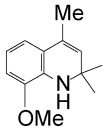
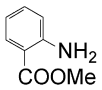
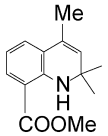
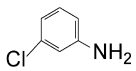
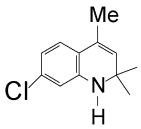
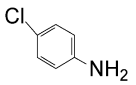
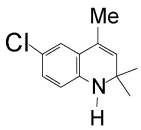
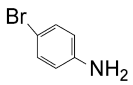
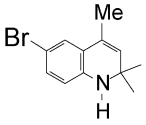
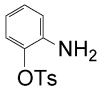
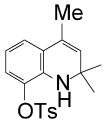
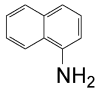
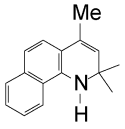
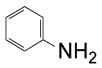
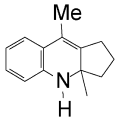
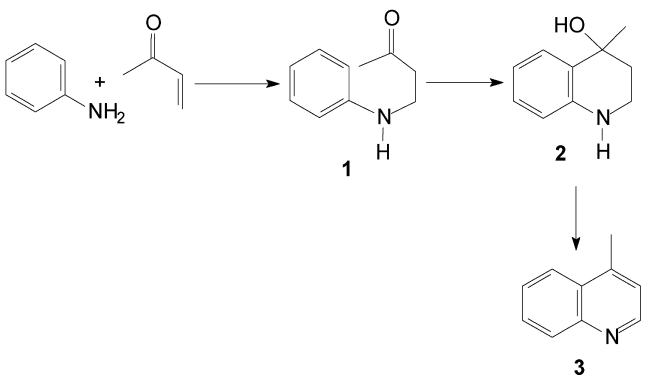
1			20		80
2			20		75
3			25		71
4			30		58
5			25		77
6			30		63
7			25		73
8			20		75
9			30		67
10			25		58
11			20		78
12			20		45

[a] Yields refer to those of pure isolated products fully characterized by spectral (IR, ^{1}H and ^{13}C NMR) and analytical data.



Scheme 2.

good scope of putting different alkyl groups in the quinoline ring by use of substituted alkyl vinyl ketones (entries 13–15). In general, the yields of quinolines are not affected by the nature of substituents on the anilines and the vinyl ketones. Interestingly, in the case of *m*-substituted anilines, only one regioisomeric quinoline corresponding to *p*-cyclization is obtained (entries 3,7,8).

The access to dihydroquinolines is not very easy as reduction of the quinoline ring by conventional reducing agents leads to 1,2,3,4-tetrahydroquinolines.[7] However, this procedure provides an efficient synthesis of a series of 2,2,4-trimethyl-1,2-dihydroquinolines with varied substituents such as Cl, Br, OMe, COOMe, Ts on the aromatic ring (Table 2). The biological activities of quinoline derivatives are greatly influenced by the nature of substituents on the aromatic ring.[1–3] A fused dihydroquinoline is also obtained by proper choice of alkyl vinyl ketone (entry 12, Table 2).

Presumably, this process involves Michael addition of aniline to the vinyl ketone[8] followed by subsequent cyclization and aromatization under the catalysis of $InCl_3$/SiO_2, as delineated in Scheme 2. The intermediate tertiary hydroxy compounds **2** formed by Michael addition followed by cyclization have been isolated in a couple of reactions and are properly characterized. These intermediates were subsequently dehydrated and aromatized to the quinolines by further microwave heating on SiO_2/$InCl_3$. This type of oxidative aromatization in the presence of Lewis acid and air is not unprecedented.[9]

In general, the reactions are fast, clean and high yielding excepting a few reactions (entry 15 in Table 1 and entries 10, 12 in Table 2) where a considerable amount of unidentified tarry materials are obtained. However, the reaction does not proceed with acrolein or other vinyl aldehydes yielding instead the corresponding imine. The reaction in the presence of indium(III) chloride alone is sluggish and the reaction on the silica gel surface without indium(III) chloride leads to imine formation only. Conventional heating in place of microwave irradiation induces considerable polymerization of vinyl ketones reducing the yields of quinolines drastically.

3. Conclusion

The present procedure catalyzed by indium(III) chloride on a silica gel surface provides an efficient one-pot synthesis of substituted quinolines and 1,2-dihydroquinolines from readily available anilines and alkyl vinyl ketones under solvent-free conditions. The notable advantages of this procedure are: (a) operational simplicity; (b) fast and clean reaction; (c) high yield; (d) general applicability accommodating a variety of substitutions on both rings. We believe that this procedure will provide a better and more practical alternative to the existing methodologies for the synthesis of quinolines.

4. Experimental

4.1. General

Melting points were determined on a glass disk with an electrical bath and are uncorrected. ^{1}H NMR (300 MHz) and ^{13}C NMR (75 MHz) spectra were run in $CDCl_3$ solutions. IR spectra were taken as neat for liquid compounds and as KBr plates for solids. Elemental analyses were done by a Perkin–Elmer autoanalyzer. Column chromatography was performed on silica gel (60–120 mesh, SRL, India). Anilines and alkyl vinyl ketones were distilled before use. Indium(III) chloride (Aldrich) was used as such. THF was distilled over potassium-benzophenone before use.

4.1.1. General procedure for the synthesis of quinolines: representative procedure for 4,6-dimethylquinoline (entry 4, Table 1). A mixture of 4-methyl aniline (214 mg, 2 mmol) and methyl vinyl ketone (175 mg, 2.5 mmol) was added to silica gel impregnated with indium(III) chloride (132 mg, 0.6 mmol), prepared by adding a solution of $InCl_3$ in minimum amount of THF to silica gel (HF_{254}, E-Merck, activated by heating for 3 h at 150°C under reduced pressure) followed by complete evaporation of solvent under vacuum. The whole mixture was stirred for 5 min for uniform mixing and was then irradiated by microwave in a domestic microwave oven (BPL, India) at 600 W (50% of total power) for 10 min (5+5 min with an intermission of 10 min in between) as required to complete the reaction (TLC). The reaction mixture was then eluted with ethyl acetate (20 mL) and the extract was washed with brine, dried over Na_2SO_4 and evaporated to leave the crude product which was purified by column chromatography over silica gel (hexane–ether 95:5) to furnish pure product, 4,6-dimethylquinoline as a yellow oil (270 mg, 85%); IR 3006, 1620, 1500 cm^{-1}; ^{1}H NMR δ 8.71 (d, J=4.1 Hz, 1H), 8.01 (d, J=8.5 Hz, 1H), 7.75 (s, 1H), 7.54 (d, J=8.5 Hz, 1H), 7.10 (d, J=4.1 Hz, 1H), 2.68 (s, 3H), 2.56 (s, 3H); ^{13}C NMR δ 148.7, 145.7, 144.1, 136.2, 131.4, 129.0, 128.5, 122.7, 121.8, 21.8, 18.6. Anal. calcd for $C_{11}H_{11}N$: C, 84.04; H, 7.05; N, 8.91. Found: C, 83.91; H, 7.01; N, 8.79.

This procedure is followed for the synthesis of all the quinolines listed in Table 1. However, in reactions with aniline (entry 1) and 2-methylaniline (entry 2) the intermediate tertiary hydroxy compounds **2** have been isolated as colorless oils. These compounds have been easily characterised by IR and ^{1}H NMR:

4.1.2. 1,2,3,4-Tetrahydro-4-hydroxy-4-methylquinoline (entry 1). IR 3600–3300 cm^{-1}; ^1H NMR δ 7.30–6.80 (m, 4H), 3.20 (m, 2H), 1.80 (broad, 2H), 1.70 (t, J=6.0 Hz, 2H), 1.30 (s, 3H).

4.1.3. 1,2,3,4-Tetrahydro-4,8-dimethyl-4-hydroxyquinoline (entry 2). IR 3600–3300 cm^{-1}; ^1H NMR δ 7.40–7.0 (m, 3H), 3.20 (m, 2H), 2.20 (s, 3H), 1.70 (t, J=6.0 Hz, 2H), 1.41 (broad, 2H), 1.32 (s, 3H).

These hydroxy compounds are then heated by microwave irradiation for the second time being absorbed on the surface of silica gel in presence of $InCl_3$ under the same experimental conditions as described above for 2 min to furnish the corresponding quinolines.

For the synthesis of dihydroquinolines also (Table 2) the same procedure is followed with microwave heating at 120 W (10% of total power) for 20–30 min. (10+10 min with an interval of 10 min in between). The products are identified by their IR, ^1H and ^{13}C NMR spectral data and elemental analysis. These data are presented below in order of their entries in Tables 1 and 2.

4.1.4. 4-Methylquinoline (entry 1, Table 1). Pale yellow oil (85%); IR 3053, 1605, 1494 cm^{-1}; ^1H NMR δ 8.78 (d, J=4.4 Hz, 1H), 8.13 (d, J=8.5 Hz, 1H), 8.02 (d, J=8.5 Hz, 1H), 7.73 (t, J=7.0 Hz, 1H), 7.58 (t, J=7.0 Hz, 1H), 7.24 (d, J=4.4 Hz, 1H), 2.72 (s, 3H).

4.1.5. 4,8-Dimethylquinoline (entry 2, Table 1). Yellow oil (81%); IR 3042, 1601, 1502 cm^{-1}; ^1H NMR δ 8.87 (d, J=4.5 Hz, 1H), 7.89 (d, J=8.4 Hz, 1H), 7.60 (d, J=7.1 Hz, 1H), 7.59 (t, J=7.1 Hz, 1H), 7.27 (d, J=4.5 Hz, 1H), 2.86 (s, 3H), 2.74 (s, 3H); ^{13}C NMR δ 148.3, 144.5, 144.3, 135.5, 130.4, 128.9, 126.7, 122.3, 122.1, 19.5, 19.1. Anal. calcd for $C_{11}H_{11}N$: C, 84.04; H, 7.05; N, 8.91. Found: C, 83.81; H, 7.09; N, 8.76.

4.1.6. 4,7-Dimethylquinoline (entry 3, Table 1). Yellow oil (84%); IR 3029, 1616, 1499 cm^{-1}; ^1H NMR δ 8.74 (d, J=4.5 Hz, 1H), 7.93 (d, J=8.5 Hz, 1H), 7.89 (s, 1H), 7.42 (d, J=8.5 Hz, 1H), 7.21 (d, J=4.5 Hz, 1H), 2.71 (s, 3H), 2.57 (s, 3H); ^{13}C NMR δ 149.5, 147.3, 146.0, 140.5, 132.8, 129.4, 124.4, 121.5, 118.5, 21.8, 18.9. Anal. calcd for $C_{11}H_{11}N$: C, 84.04; H, 7.05; N, 8.91. Found: C, 84.01; H, 6.93; N, 8.83.

4.1.7. 8-Methoxy-4-methylquinoline (entry 5, Table 1). Yellow oil (80%); IR 3084, 1616, 1519 cm^{-1}; ^1H NMR δ 8.75 (d, J=4.5 Hz, 1H), 8.01 (d, J=6.0 Hz, 1H), 7.46 (t, J=6.0 Hz, 1H), 7.24–7.19 (m, 2H), 3.89 (s, 3H), 2.69 (s, 3H); ^{13}C NMR δ 155.4, 148.2, 140.4, 135.7, 128.3, 125.6, 122.5, 118.3, 109.1, 54.1, 18.1. Anal. calcd for $C_{11}H_{11}NO$: C, 76.28; H, 6.40; N, 8.09. Found: C, 76.12; H, 6.31; N, 8.01.

4.1.8. 6-Methoxy-4-methylquinoline (entry 6, Table 1). Yellow oil (83%); IR 3021, 1617, 1496 cm^{-1}; ^1H NMR δ 8.63 (d, J=4.4 Hz, 1H), 8.02 (d, J=9.2 Hz, 1H), 7.38 (d, J=9.2 Hz, 1H), 7.21–7.18 (m, 2H), 3.95 (s, 3H), 2.66 (s, 3H); ^{13}C NMR δ 156.0, 145.8, 142.0, 141.1, 127.6, 127.5, 120.4, 119.8, 110.2, 53.8, 17.2. Anal. calcd for $C_{11}H_{11}NO$: C, 76.28; H, 6.40; N, 8.09. Found: C, 76.21; H, 6.27; N, 7.99.

4.1.9. 7-Hydroxy-4-methylquinoline (entry 7, Table 1). Yellow oil (81%); IR 3388, 1601, 1502 cm^{-1}; ^1H NMR δ 8.78 (d, J=6.0 Hz, 1H), 8.14 (d, J=1.2 Hz, 1H), 7.94 (d, J=9.0 Hz, 1H), 7.54 (d, J=9.0 Hz, 1H), 7.27 (m, 2H), 2.72 (s, 3H); ^{13}C NMR δ 155.8, 150.2, 142.5, 140.2, 132.5, 127.8, 122.4, 121.9, 110.2, 17.8. Anal. calcd for $C_{10}H_9NO$: C, 75.45; H, 5.70; N, 8.80. Found: C, 75.32; H, 5.65; N, 8.65.

4.1.10. 7-Chloro-4-methylquinoline (entry 8, Table 1). Yellow oil (87%); IR 3004, 1624, 1596 cm^{-1}; ^1H NMR δ 8.77 (d, J=4.2 Hz, 1H), 8.14 (d, J=1.8 Hz, 1H), 7.94 (d, J=9.0 Hz, 1H), 7.53 (dd, J=9.0, 1.8 Hz, 1H), 7.25 (d, J=4.2 Hz, 1H), 2.71 (s, 3H); ^{13}C NMR δ 150.5, 147.5, 145.3, 135.3, 129.3, 128.1, 127.4, 125.2, 122.0, 18.6. Anal. calcd for $C_{10}H_8NCl$: C, 67.62; H, 4.54; N, 7.89. Found: C, 67.51; H, 4.51; N, 7.81.

4.1.11. 6-Chloro-4-methylquinoline (entry 9, Table 1). Yellow oil (80%); IR 3019, 1601, 1503 cm^{-1}; ^1H NMR δ 8.76 (d, J=3.2 Hz, 1H), 8.05 (d, J=8.9 Hz, 1H), 7.97 (d, J=2.3 Hz, 1H), 7.64 (dd, J=8.9, 2.3 Hz, 1H), 7.25 (d, J=3.2 Hz, 1H), 2.68 (s, 3H); ^{13}C NMR δ 150.6, 146.6, 144.0, 132.6, 131.9, 130.4, 123.3, 122.9, 118.1, 18.7. Anal. calcd for $C_{10}H_8NCl$: C, 67.62; H, 4.54; N, 7.89. Found: C, 67.54; H, 4.42; N, 7.78.

4.1.12. 6-Bromo-4-methylquinoline (entry 10, Table 1). Yellow oil (80%); IR 3031, 1623, 1509 cm^{-1}; ^1H NMR δ 8.79 (d, J=4.5 Hz, 1H), 8.15 (d, J=2.1 Hz, 1H), 8.04 (d, J=9.0 Hz, 1H), 7.78 (dd, J=9.0, 2.1 Hz, 1H), 7.29 (d, J=4.5 Hz, 1H), 2.68 (s, 3H); ^{13}C NMR δ 149.6, 145.5, 144.5, 132.9, 130.8, 129.4, 126.2, 122.5, 120.7, 18.6. Anal. calcd for $C_{10}H_8NBr$: C, 54.08; H, 3.63; N, 6.31. Found: C, 53.95; H, 3.59; N, 6.22.

4.1.13. 6-Iodo-8,4-dimethylquinoline (entry 11, Table 1). Yellow oil (83%), IR 3053, 1608, 1492 cm^{-1}; ^1H NMR δ 8.78 (d, J=4.5 Hz, 1H), 8.20 (d, J=1.5 Hz, 1H), 7.81 (d, J=1.5 Hz, 1H), 7.21 (d, J=4.5 Hz, 1H), 2.71 (s, 3H), 2.63 (s, 3H); ^{13}C NMR δ 149.1, 145.7, 143.5, 139.6, 137.7, 130.8, 126.8, 122.2, 92.2, 18.9, 18.0. Anal. calcd for $C_{11}H_{10}NI$: C, 46.67; H, 3.56; N, 4.95. Found: C, 46.58; H, 3.51; N, 4.88.

4.1.14. 4-Methyl-7,8-benzoquinoline (entry 12, Table 1). Yellow oil (82%); IR 3039, 1601, 1504 cm^{-1}; ^1H NMR δ 9.31 (d, J=8.1 Hz, 1H), 8.85 (d, J=4.5 Hz, 1H), 7.90–7.65 (m, 5H), 7.34 (d, J=4.5 Hz, 1H), 2.76 (s, 3H); ^{13}C NMR δ 148.0, 147.1, 144.0, 133.2, 128.1, 127.5, 126.9, 126.7, 125.7, 125.1, 123.9, 122.8, 121.7, 19.7. Anal. calcd for $C_{14}H_{11}N$: C, 87.01; H, 5.74; N, 7.25. Found: C, 86.94; H, 5.69; N, 7.21.

4.1.15. 4-(4-Methoxyphenyl)-2-methylquinoline (entry 13, Table 1). Yellow oil (81%); IR 3053, 1593, 1448 cm^{-1}; ^1H NMR δ 8.03 (d, J=8.7 Hz, 1H), 7.92 (d, J=11.4 Hz, 2H), 7.69 (d, J=8.7 Hz, 1H), 7.44 (d, J=8.7 Hz, 1H), 7.29 (m, 1H), 7.03 (m, 1H), 6.90 (d, J=11.4 Hz, 2H), 3.85 (s, 3H), 2.75 (s, 3H); ^{13}C NMR δ 136.3, 130.6 (2C),

130.4, 129.2, 128.6, 127.3, 127.0, 125.8, 124.7, 114.7, 114.2 (2C), 113.5, 113.0, 55.3, 24.0. Anal. calcd for $C_{17}H_{15}NO$: C, 81.90; H, 6.06; N, 5.62. Found: C, 81.75; H, 6.01; N, 5.54.

4.1.16. 7-Chloro-4-(4-methoxyphenyl)-2-methylquinoline (entry 14, Table 1). Yellow oil (83%); IR 3044, 1623, 1501 cm^{-1}; ^1H NMR δ 8.14 (d, J=1.9 Hz, 1H), 7.94 (d, J=11.2 Hz, 2H), 7.51 (d, J=9.0 Hz, 1H), 7.25–6.92 (m, 4H), 3.82 (s, 3H), 2.77 (s, 3H); ^{13}C NMR δ 148.9, 146.8, 144.2, 133.5, 131.1 (2C), 129.2, 128.6, 127.5, 127.1, 124.8, 115.4 (2C), 114.0, 113.7, 55.3, 26.2. Anal. calcd for $C_{17}H_{14}NOCl$: C, 71.96; H, 4.97; N, 4.94. Found: C, 71.81; H, 4.91; N, 4.88.

4.1.17. 3-Ethyl-4-methyl-2-propylquinoline (entry 15, Table 1). Yellow oil (55%); IR 3111, 1625, 1483 cm^{-1}; ^1H NMR δ 8.04 (d, J=8.4 Hz, 1H), 7.66 (d, J=8.4 Hz, 1H), 7.58 (t, J=7.0 Hz, 1H), 7.38 (t, J=7.0 Hz, 1H), 2.89 (t, J=7.6 Hz, 2H), 2.71 (s, 3H), 2.68 (q, J=7.2 Hz, 2H), 1.83 (m, 2H), 1.18 (t, J=7.6 Hz, 3H), 1.04 (t, J=7.2 Hz, 3H); ^{13}C NMR δ 139.5, 134.1, 130.2, 128.5, 128.3, 127.1, 126.9, 124.7, 122.3, 38.6, 25.1, 22.4, 18.4, 14.6, 14.1. Anal. calcd for $C_{15}H_{19}N$: C, 84.46; H, 8.98; N, 6.57. Found: C, 84.30; H, 8.91; N, 6.49.

4.1.18. 2,2,4-Trimethyl-1,2-dihydroquinoline (entry 1, Table 2). Colorless oil (80%); IR 3365 cm^{-1}; ^1H NMR δ 7.07 (dd, J=1.4, 7.6 Hz, 1H), 6.99 (dt, J=1.4, 7.6 Hz, 1H), 6.64 (dt, J=1.1, 7.5 Hz, 1H), 6.46 (dt, J=1.1, 7.5 Hz, 1H), 5.32 (d, J=1.3 Hz, 1H), 1.99 (d, J=1.3 Hz, 3H), 1.27 (s, 6H); ^{13}C NMR δ 143.5, 128.9, 128.7 (2C), 124.0, 122.0, 117.7, 113.4, 52.2, 31.2 (2C), 18.9. Anal. calcd for $C_{12}H_{15}N$: C, 83.19; H, 8.73; N, 8.08. Found: C, 83.01; H, 8.55; N, 8.00.

4.1.19. 2,2,4,8-Tetramethyl-1,2-dihydroquinoline (entry 2, Table 2). Colorless oil (75%); IR 3408 cm^{-1}; ^1H NMR δ 6.94 (d, J=7.6 Hz, 1H), 6.89 (d, J=7.6 Hz, 1H), 6.55–6.50 (m, 1H), 5.27 (s, 1H), 2.06 (s, 3H), 1.98 (s, 3H), 1.28 (s, 6H); ^{13}C NMR δ 141.5, 130.2, 129.3, 128.0 (2C), 121.1, 116.7, 96.6, 52.1, 31.9 (2C), 19.3, 17.4. Anal. calcd for $C_{13}H_{17}N$: C, 83.37; H, 9.15; N, 7.48. Found: C, 83.18; H, 9.01; N, 7.27.

4.1.20. 2,2,4,7-Tetramethyl-1,2-dihydroquinoline (entry 3, Table 2). Colorless oil (71%); IR 3367 cm^{-1}; ^1H NMR δ 6.96 (d, J=7.7 Hz, 1H), 6.46 (d, J=7.7 Hz, 1H), 6.28 (s, 1H), 5.26 (d, J=1.2 Hz, 1H), 2.23 (s, 3H), 1.98 (d, J=1.2 Hz, 3H), 1.27 (s, 6H); ^{13}C NMR δ 143.6, 128.9, 127.8, 123.9, 119.5, 118.4, 113.9, 110.1, 52.2, 31.4 (2C), 21.7, 18.9. Anal. calcd for $C_{13}H_{17}N$: C, 83.37; H, 9.15; N, 7.48. Found: C, 83.20; H, 8.98; N, 7.29.

4.1.21. 2,2,3,6-Tetramethyl-1,2-dihydroquinoline (entry 4, Table 2). Colorless oil (58%); IR 3367 cm^{-1}; ^1H NMR δ 6.86 (s, 1H), 6.78 (dd, J=2.3, 7.8 Hz, 1H), 6.34 (d, J=7.8 Hz, 1H), 5.29 (d, J=1.0 Hz, 1H), 2.22 (s, 3H), 1.97 (d, J=1.0 Hz, 3H), 1.24 (s, 6H); ^{13}C NMR δ 141.4, 129.2, 129.1, 129.0, 126.6, 124.6, 113.4, 96.5, 52.1, 31.2 (2C), 21.1, 19.0. Anal. calcd for $C_{13}H_{17}N$: C, 83.37; H, 9.15; N, 7.48. Found: C, 83.17; H, 8.97; N, 7.29.

4.1.22. 8-Methoxy-2,2,4-trimethyl-1,2-dihydroquinoline (entry 5, Table 2). Yellowish oil (77%); IR 3384, 1606 cm^{-1}; ^1H NMR δ 6.73 (d, J=7.7 Hz, 1H), 6.64 (d, J=8.0 Hz, 1H), 6.51 (dd, J=7.7, 8.0 Hz, 1H), 5.27 (s, 1H), 3.78 (s, 3H), 1.98 (s, 3H), 1.26 (s, 6H); ^{13}C NMR δ 145.8, 133.4, 128.9, 128.5, 116.6, 115.9, 109.9, 96.6, 55.9, 31.6 (2C), 19.3. Anal. calcd for $C_{13}H_{17}NO$: C, 76.81; H, 8.43; N, 6.89. Found: C, 76.66; H, 8.24; N, 6.68.

4.1.23. 8-Carbomethoxy-2,2,4-trimethyl-1,2-dihydroquinoline (entry 6, Table 2). Colorless oil (63%); IR 3327, 1681 cm^{-1}; ^1H NMR δ 7.90 (broad, 1H), 7.66 (d, J=8.2 Hz, 1H), 7.10 (d, J=7.3 Hz, 1H), 6.43 (t, J=7.3 Hz, 1H), 5.32 (s, 1H), 3.83 (s, 3H), 1.96 (s, 3H), 1.33 (s, 6H); ^{13}C NMR δ 169.4, 147.7, 130.9, 128.8, 128.4, 127.9, 122.3, 114.2, 96.6, 52.2, 51.7, 32.8 (2C), 19.4. Anal. calcd for $C_{14}H_{17}NO_2$: C, 72.70; H, 7.41; N, 6.06. Found: C, 72.52; H, 7.29; N, 6.01.

4.1.24. 7-Chloro-2,2,4-trimethyl-1,2-dihydroquinoline (entry 7, Table 2). Pale yellow crystal (73%); mp 56–60°C; IR 3382, 829 cm^{-1}; ^1H NMR δ 6.53 (d, J=8.1 Hz, 1H), 6.54 (dd, J=1.9, 8.1 Hz, 1H), 6.36 (d, J=1.9 Hz, 1H), 5.30 (d, J=1.0 Hz, 1H), 1.94 (d, J=1.0 Hz, 3H), 1.22 (s, 6H); ^{13}C NMR δ 144.7, 134.0, 128.7, 128.2, 125.0, 117.3, 112.8, 96.6, 52.5, 31.7 (2C), 18.9. Anal. calcd for $C_{12}H_{14}NCl$: C, 69.39; H, 9.15; N, 7.48. Found: C, 69.18; H, 9.00; N, 7.29.

4.1.25. 6-Chloro-2,2,4-trimethyl-1,2-dihydroquinoline (entry 8, Table 2). Colorless oil (75%); IR 3375, 2243, 738 cm^{-1}; ^1H NMR δ 7.00 (d, J=2.3 Hz, 1H), 6.93–6.90 (m, 1H), 6.37 (d, J=7.9 Hz, 1H), 5.30 (s, 1H), 1.95 (s, 3H), 1.26 (s, 6H); ^{13}C NMR δ 143.6, 132.9, 129.9, 128.2, 123.8, 118.4, 114.2, 96.2, 51.7, 31.3 (2C), 18.8. Anal. calcd for $C_{12}H_{14}NCl$: C, 69.39; H, 9.15; H, 7.48. Found: C, 69.20; H, 8.95; N, 7.31.

4.1.26. 6-Bromo-2,2,4-trimethyl-1,2-dihydroquinoline (entry 9, Table 2). Pale yellow crystal (67%); mp 78°C; IR 3371, 759 cm^{-1}; ^1H NMR δ 7.12 (d, J=2.2 Hz, 1H), 7.04 (dd, J=2.2, 8.3 Hz, 1H), 6.30 (d, J=8.3 Hz, 1H), 5.33 (d, J=1.1 Hz, 1H), 1.94 (d, J=1.1 Hz, 3H), 1.26 (s, 6H); ^{13}C NMR δ 142.6, 131.1, 129.8, 128.1, 126.7, 123.8, 114.7, 109.1, 52.4, 31.4 (2C), 18.9. Anal. calcd for $C_{12}H_{14}NBr$: C, 57.16; H, 5.60; N, 5.55. Found: C, 57.01; H, 5.48; N, 5.36.

4.1.27. 8-Tosyl-2,2,3-trimethyl-1,2-dihydroquinoline (entry 10, Table 2). Colorless oil (58%); IR 3406, 2256 cm^{-1}; ^1H NMR δ 7.77 (d, J=8.4 Hz, 2H), 7.32 (d, J=8.4 Hz, 2H), 6.90 (dd, J=0.7, 7.7 Hz, 1H), 6.69 (dd, J=0.7, 7.7 Hz, 1H), 6.41 (t, J=7.7 Hz, 1H), 5.26 (s, 1H), 4.00 (broad, 1H), 2.44 (s, 3H), 1.93 (s, 3H), 1.26 (s, 6H); ^{13}C NMR δ 145.9, 135.6, 130.2 (2C), 130.1, 129.9, 128.9 (2C), 128.0, 123.8, 122.4, 122.0, 115.6, 107.4, 52.1, 31.6 (2C), 19.1, 14.5. Anal. calcd for $C_{19}H_{21}NSO_2$: C, 69.69; H, 6.46; N, 4.28. Found: C, 69.48; H, 6.38; N, 4.10.

4.1.28. 2,2,4-Trimethyl-1,2-dihydro-[7,8]-benzoquinoline (entry 11, Table 2). Colorless oil (78%); IR 3417 cm^{-1}; ^1H NMR δ 7.82–7.78 (m, 2H), 7.48–7.41 (m, 3H), 7.26 (d, J=8.5 Hz, 1H), 5.44 (d, J=0.8 Hz, 1H), 2.20 (d, J=0.8 Hz, 3H), 1.45 (s, 6H); ^{13}C NMR δ 138.6, 134.5, 129.8, 129.2, 126.9, 125.9, 125.1, 123.0, 122.3, 120.3, 116.7, 116.1, 52.5, 31.6 (2C), 19.7. Anal. calcd for

$C_{16}H_{17}N$: C, 86.05; H, 7.67; N, 6.27. Found: C, 85.87; H, 7.46; N, 6.05.

4.1.29. 2,4-Dimethyl-1,2-dihydrocyclopenta[*b*]quinoline (entry 12, Table 2). Colorless oil (45%); IR (neat) 3381 cm^{-1}; ^1H NMR δ 7.09–6.96 (m, 2H), 6.70 (m, 1H), 6.54–6.51 (m, 1H), 1.88 (s, 3H), 1.26–0.83 (m, 9H); ^{13}C NMR δ 142.8, 139.8, 126.9, 124.4, 123.1, 121.0, 118.1, 113.7, 59.5, 41.8, 27.4, 24.5, 21.7, 14.3. Anal. calcd for $C_{14}H_{17}N$: C, 84.37; H, 8.60; N, 7.03. Found: C, 84.18; H, 8.39; N, 6.91.

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